

US011364067B2

(12) **United States Patent**
Murrell et al.

(10) **Patent No.: US 11,364,067 B2**
(45) **Date of Patent: Jun. 21, 2022**

(54) **ELECTRICAL ISOLATION OF
ELECTROSURGICAL INSTRUMENTS**

18/16; A61B 2018/00077; A61B
2018/00589; A61B 2018/00595; A61B
2018/00601; A61B 2018/1253; A61B
2018/126

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USPC 248/291.1
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 869 days.

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(65) **Prior Publication Data**

US 2019/0105099 A1 Apr. 11, 2019

(51) **Int. Cl.**
A61B 18/14 (2006.01)
A61B 34/00 (2016.01)
(Continued)

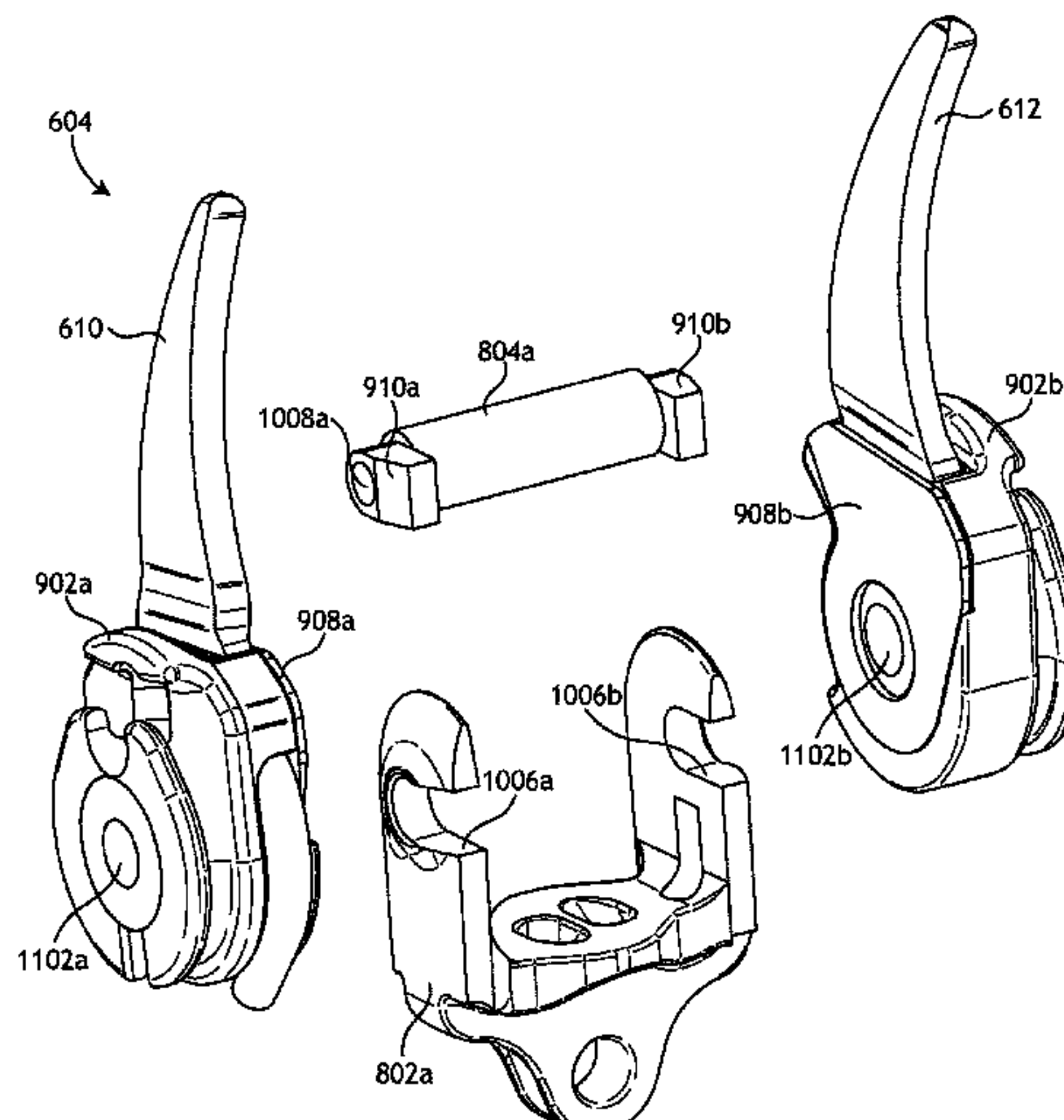
(52) **U.S. Cl.**
CPC **A61B 18/1445** (2013.01); **A61B 34/30**
(2016.02); **A61B 34/37** (2016.02); **A61B 34/71**
(2016.02); **A61B 34/74** (2016.02); **A61B**
2017/00473 (2013.01); **A61B 2018/00077**
(2013.01); **A61B 2018/00083** (2013.01); **A61B**
2018/00208 (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61B 18/1445; A61B 18/12; A61B 18/14;
A61B 2034/305; A61B 34/74; A61B
34/30; A61B 34/37; A61B 18/1206; A61B
34/71; A61B 2018/00083; A61B
2018/00208; A61B 2018/1422; A61B
2018/146; A61B 2017/00473; A61B

(57) **ABSTRACT**

A surgical tool that includes a drive housing, an elongate shaft that extends from the drive housing, and an end effector arranged at a distal end of the elongate shaft and having a jaw and a jaw holder that secures the jaw. A wrist couples the end effector to the elongate shaft and includes a distal clevis having an axle that rotatably mounts the jaw holder to the distal clevis. An electrical conductor extends from the drive housing and supplies electrical energy to the jaw via a supply conductor. At least one of the jaw holder and the axle is made of a non-conductive material that insulates the distal clevis from the electrical energy provided to the jaw.

21 Claims, 22 Drawing Sheets



- (51) **Int. Cl.**
A61B 34/30 (2016.01)
A61B 34/37 (2016.01)
A61B 18/00 (2006.01)
A61B 17/00 (2006.01)
A61B 18/12 (2006.01)
- (52) **U.S. Cl.**
CPC *A61B 2018/00589* (2013.01); *A61B 2018/00595* (2013.01); *A61B 2018/00601* (2013.01); *A61B 2018/126* (2013.01); *A61B 2018/1253* (2013.01); *A61B 2018/146* (2013.01); *A61B 2018/1422* (2013.01); *A61B 2034/305* (2016.02)

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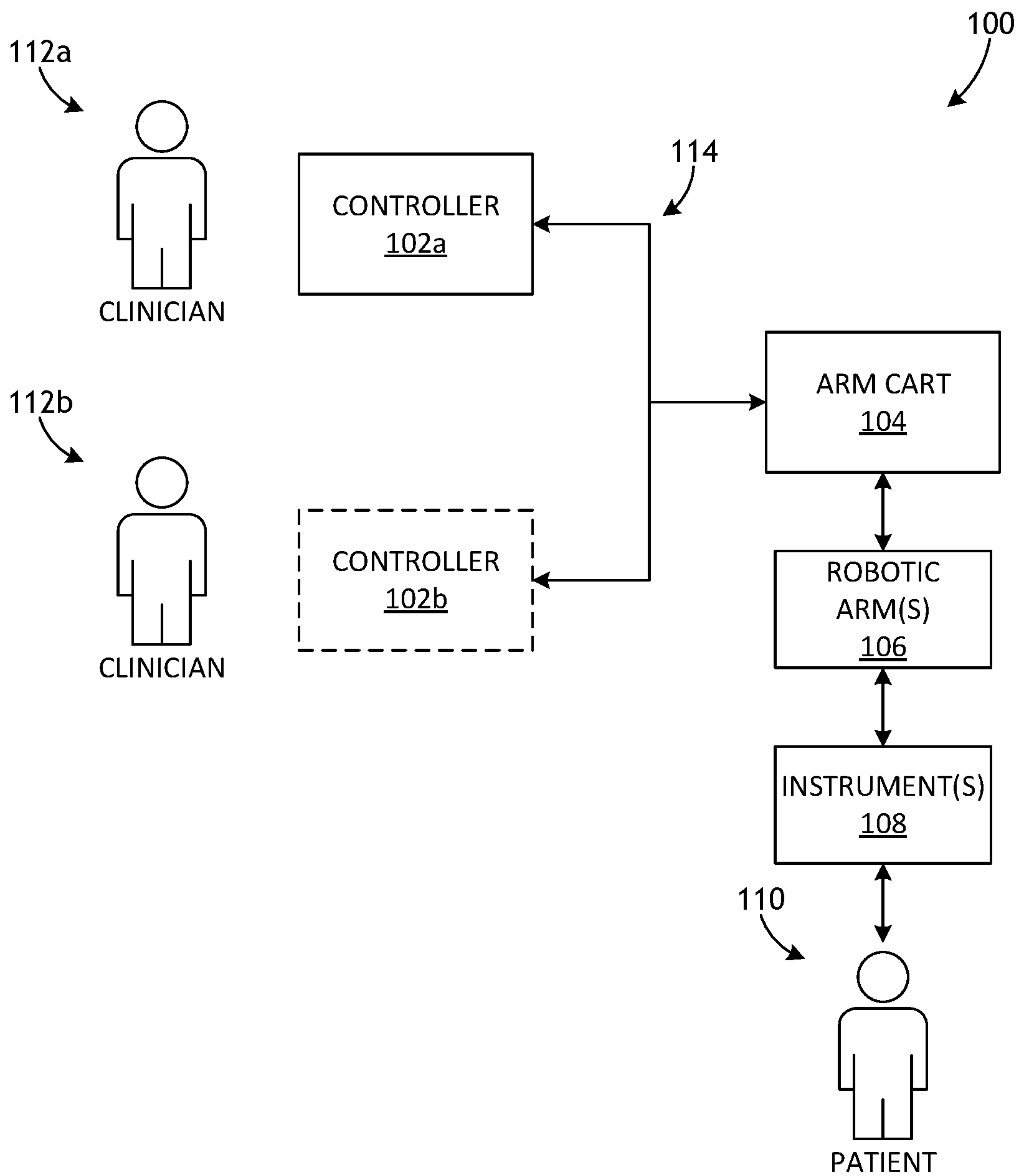


FIG. 1

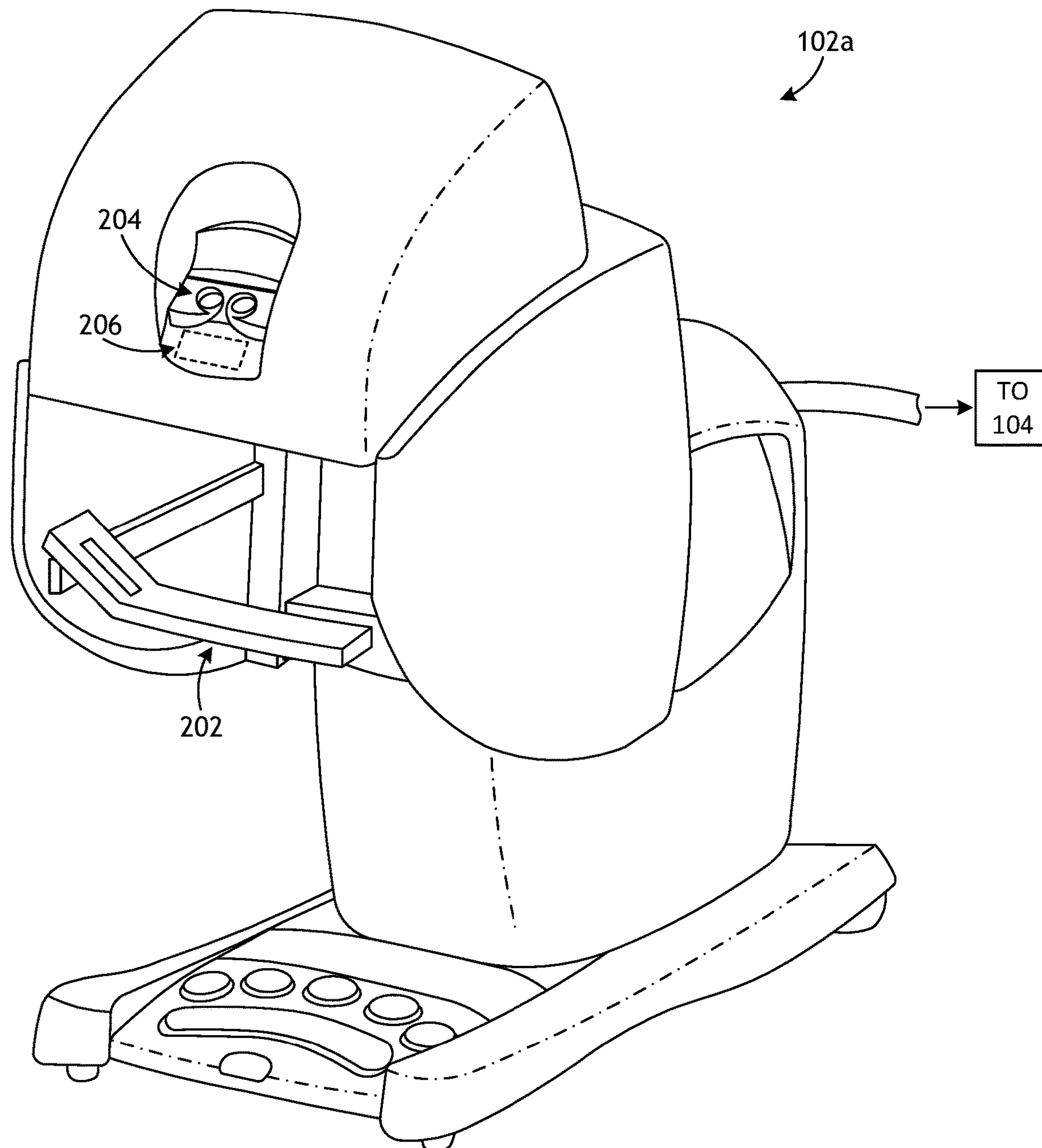


FIG. 2

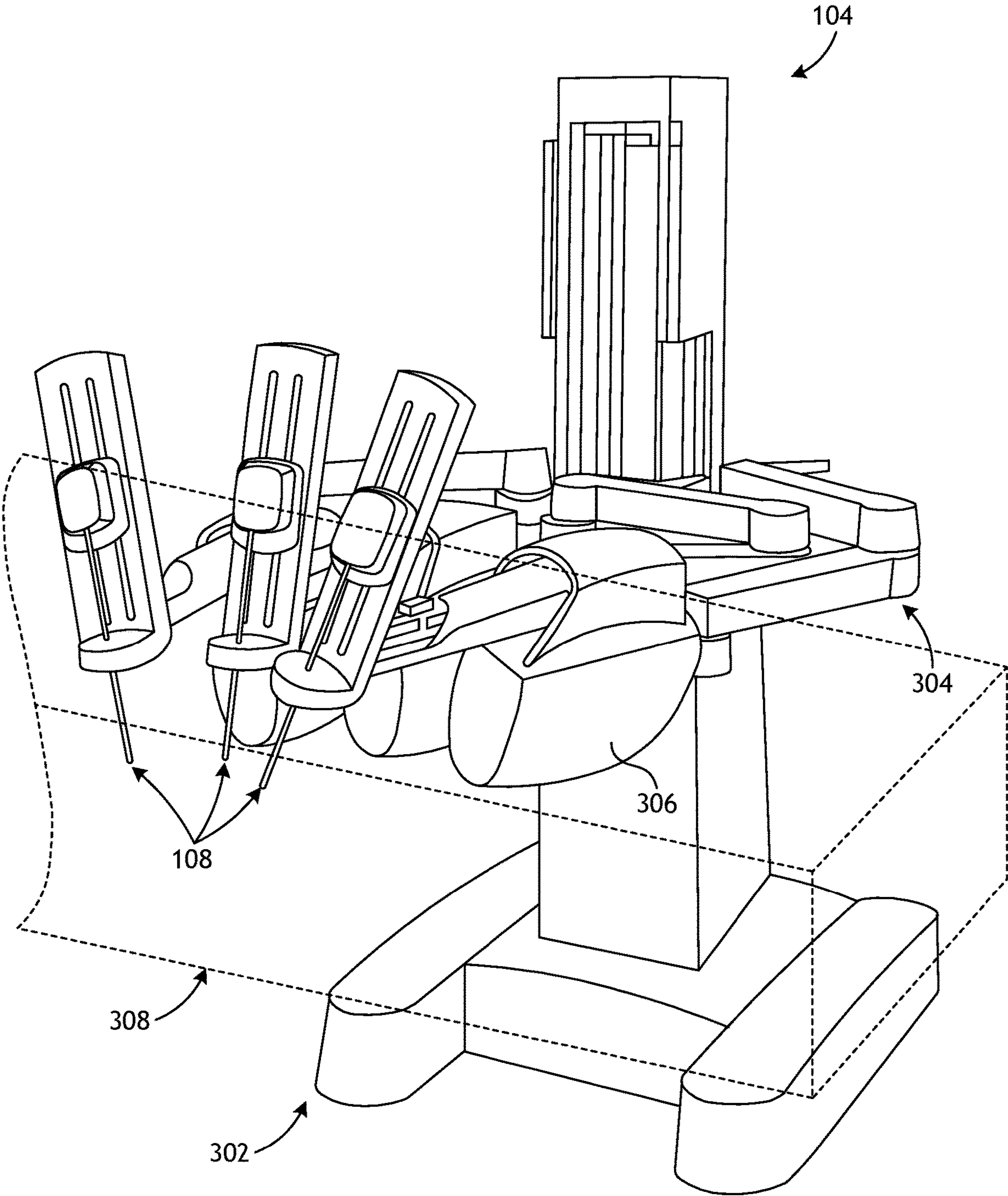


FIG. 3

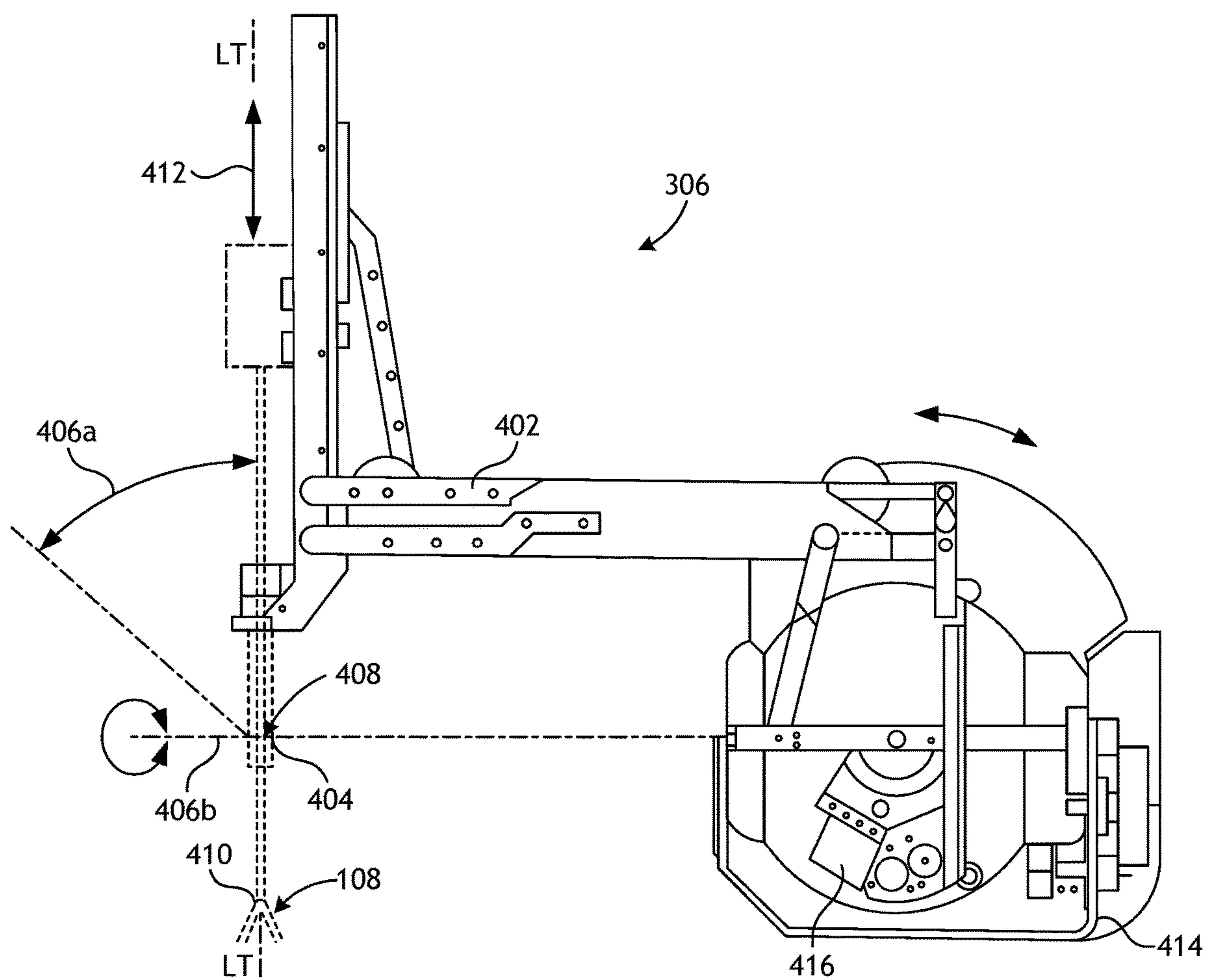


FIG. 4

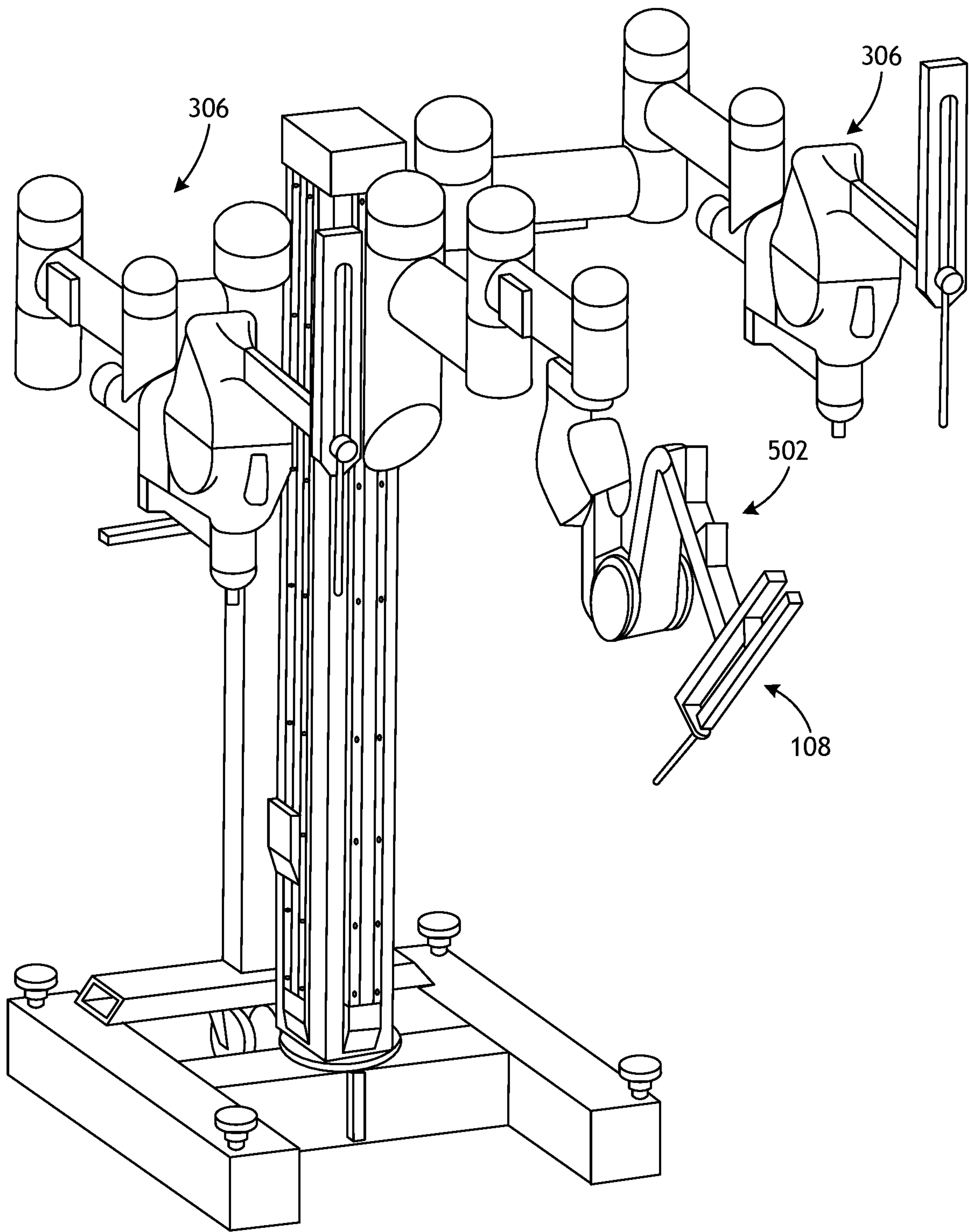
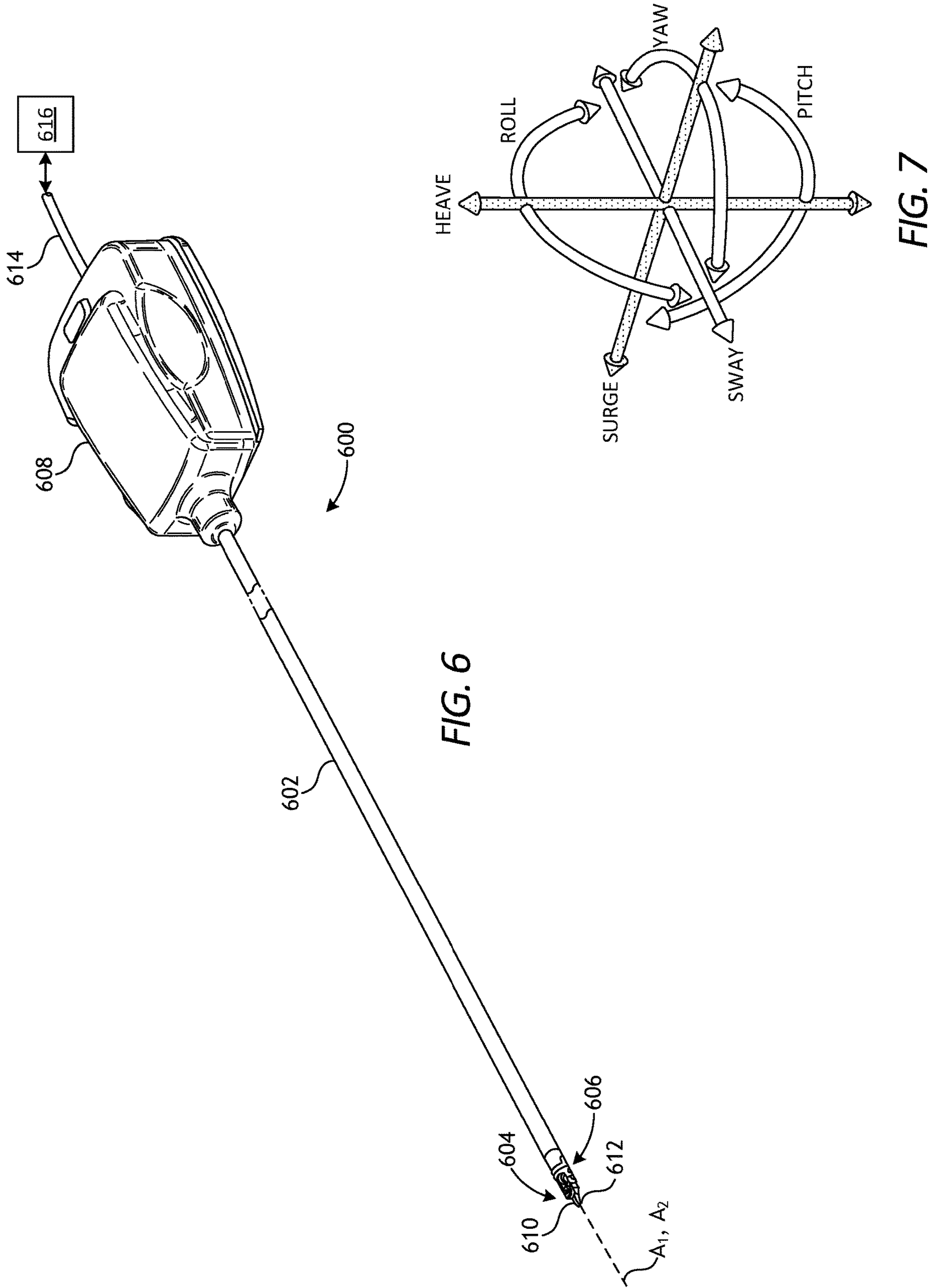


FIG. 5



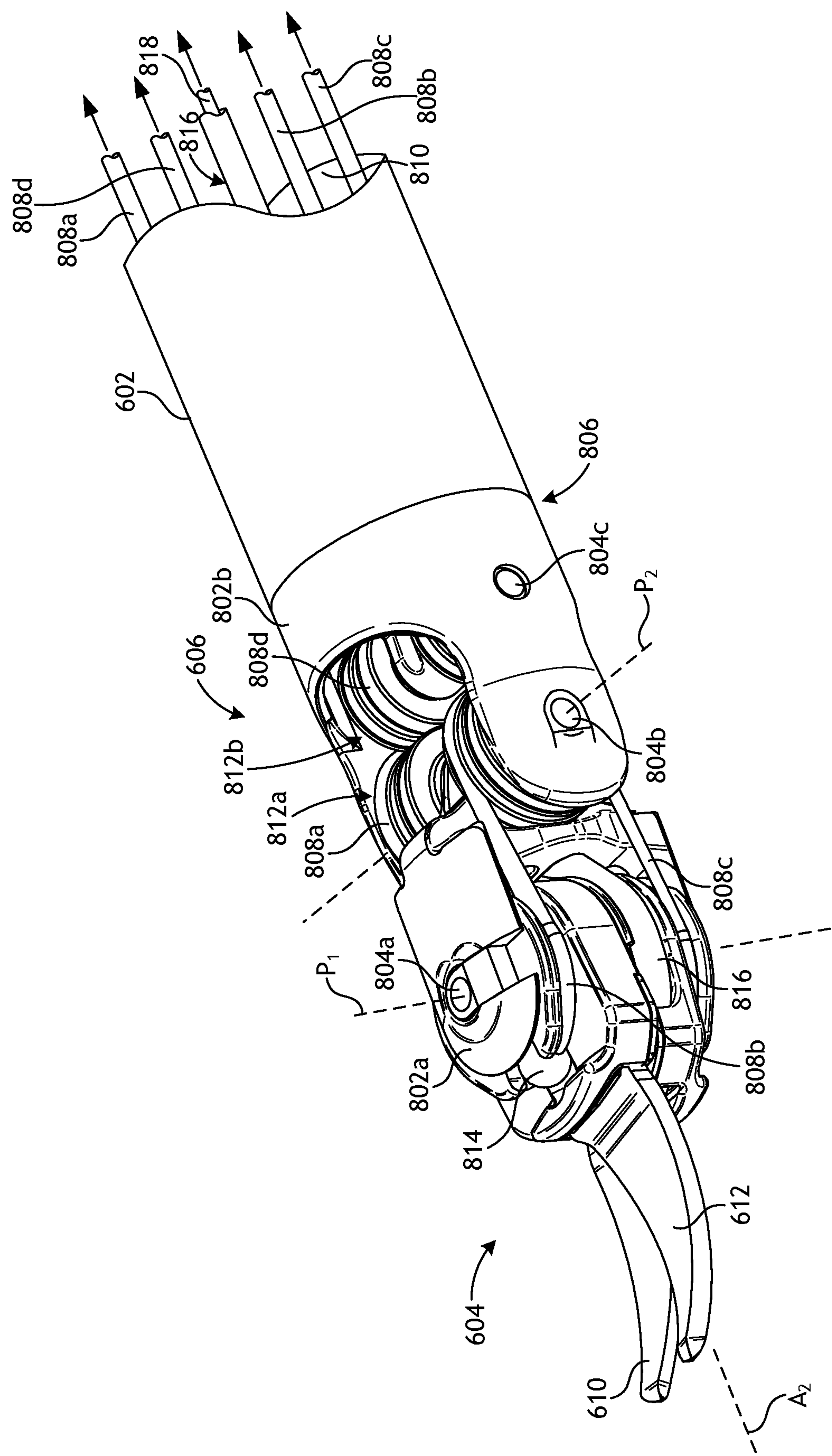


FIG. 8

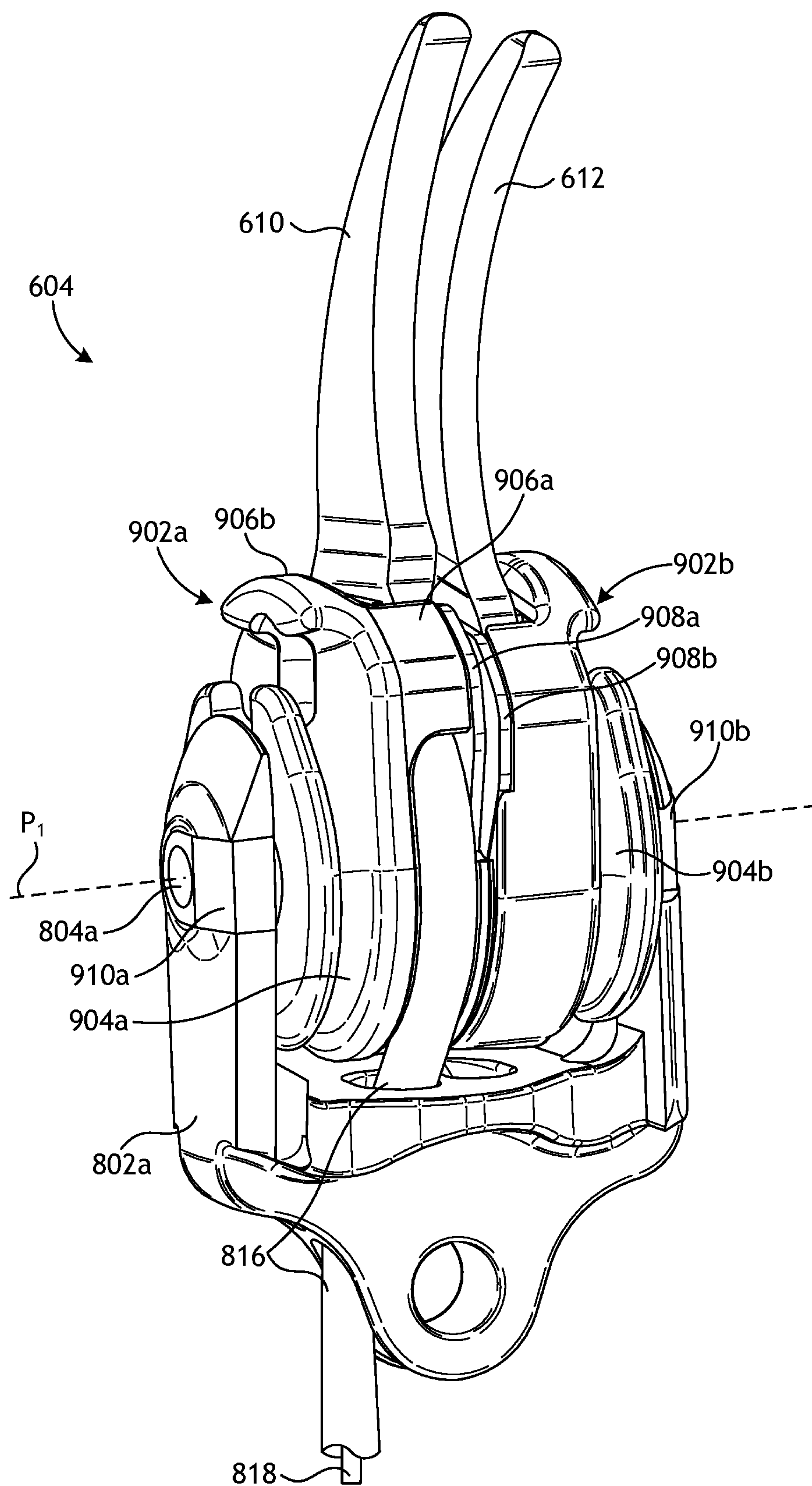


FIG. 9

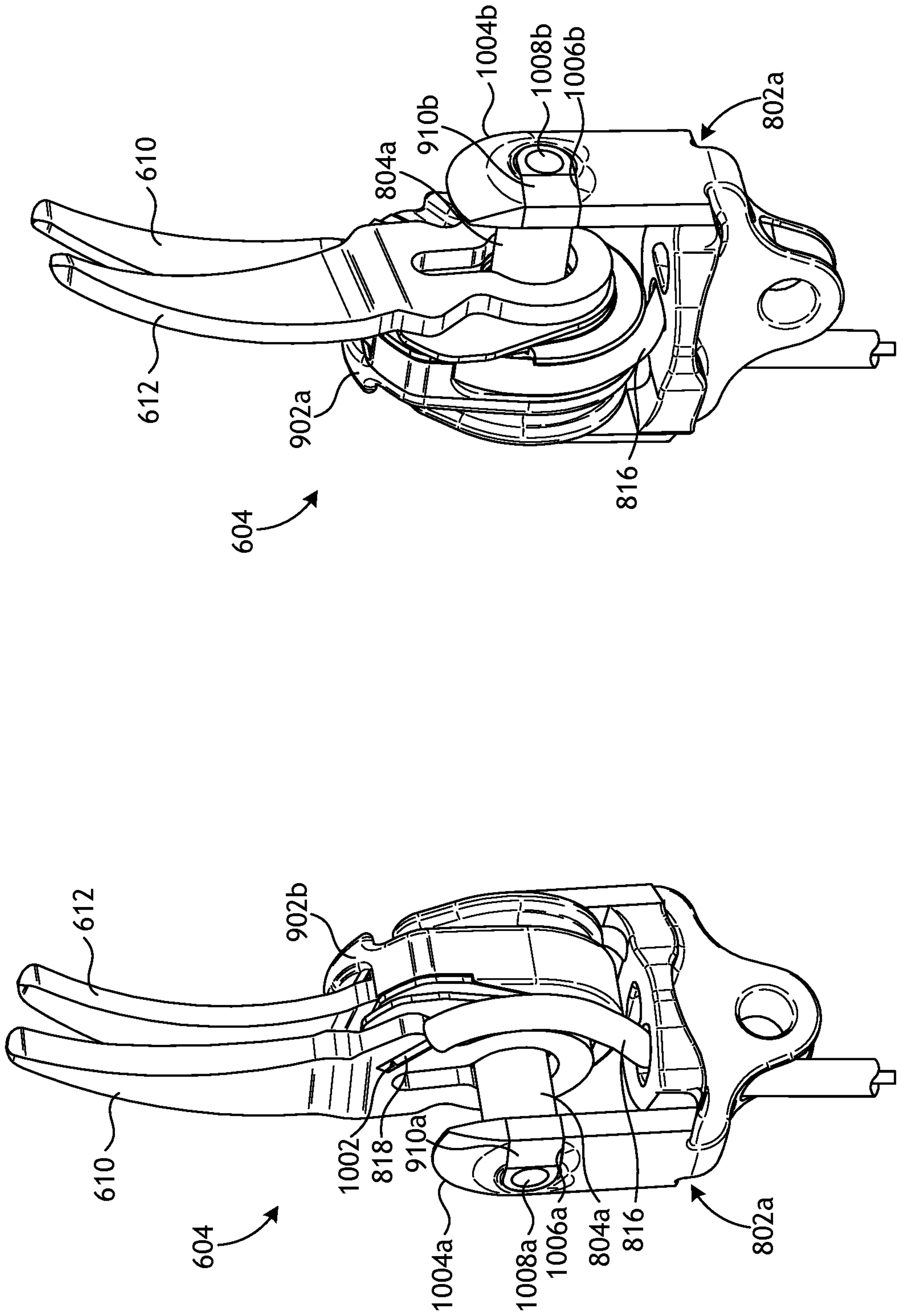


FIG. 10B

FIG. 10A

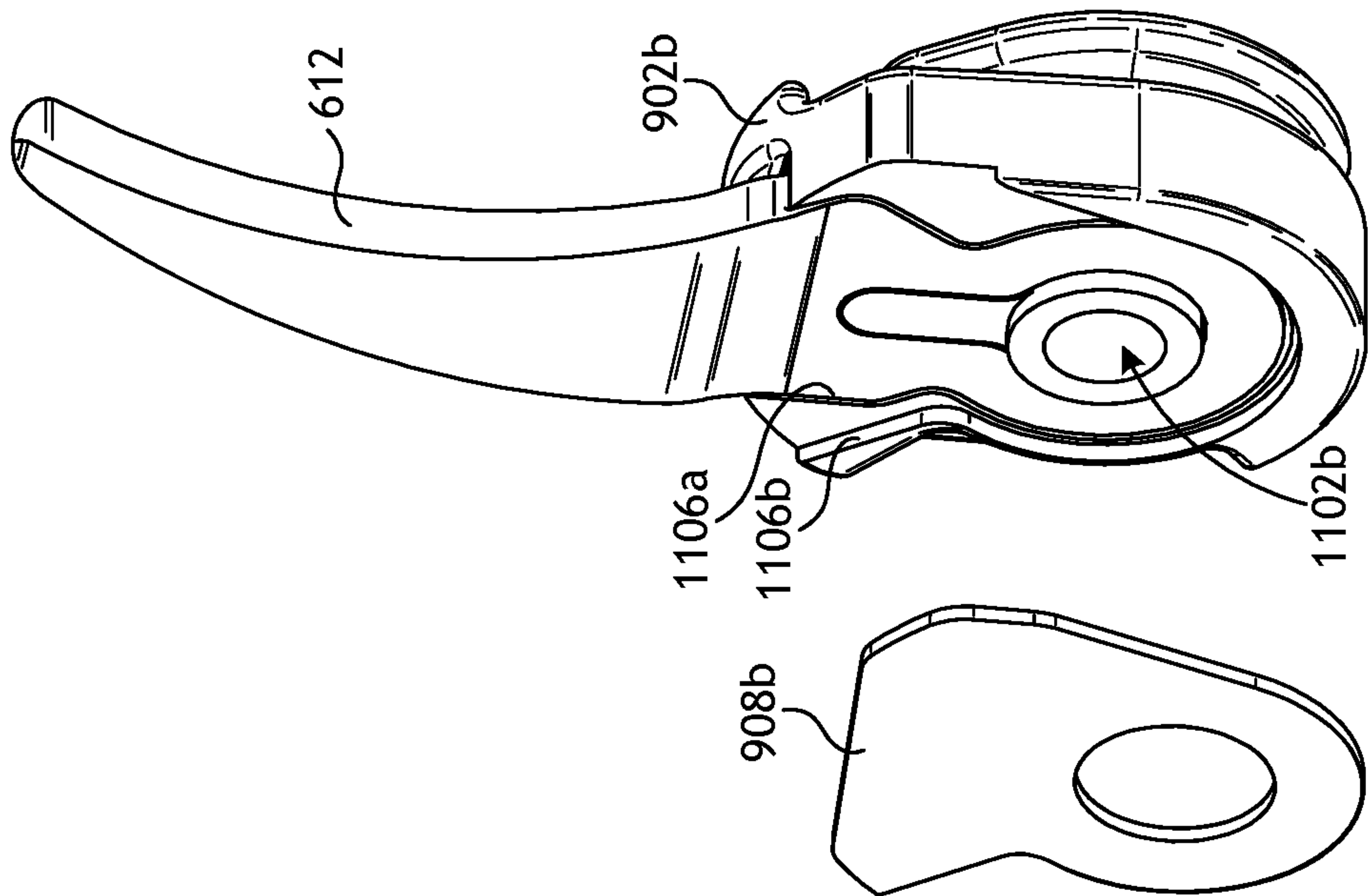


FIG. 11B

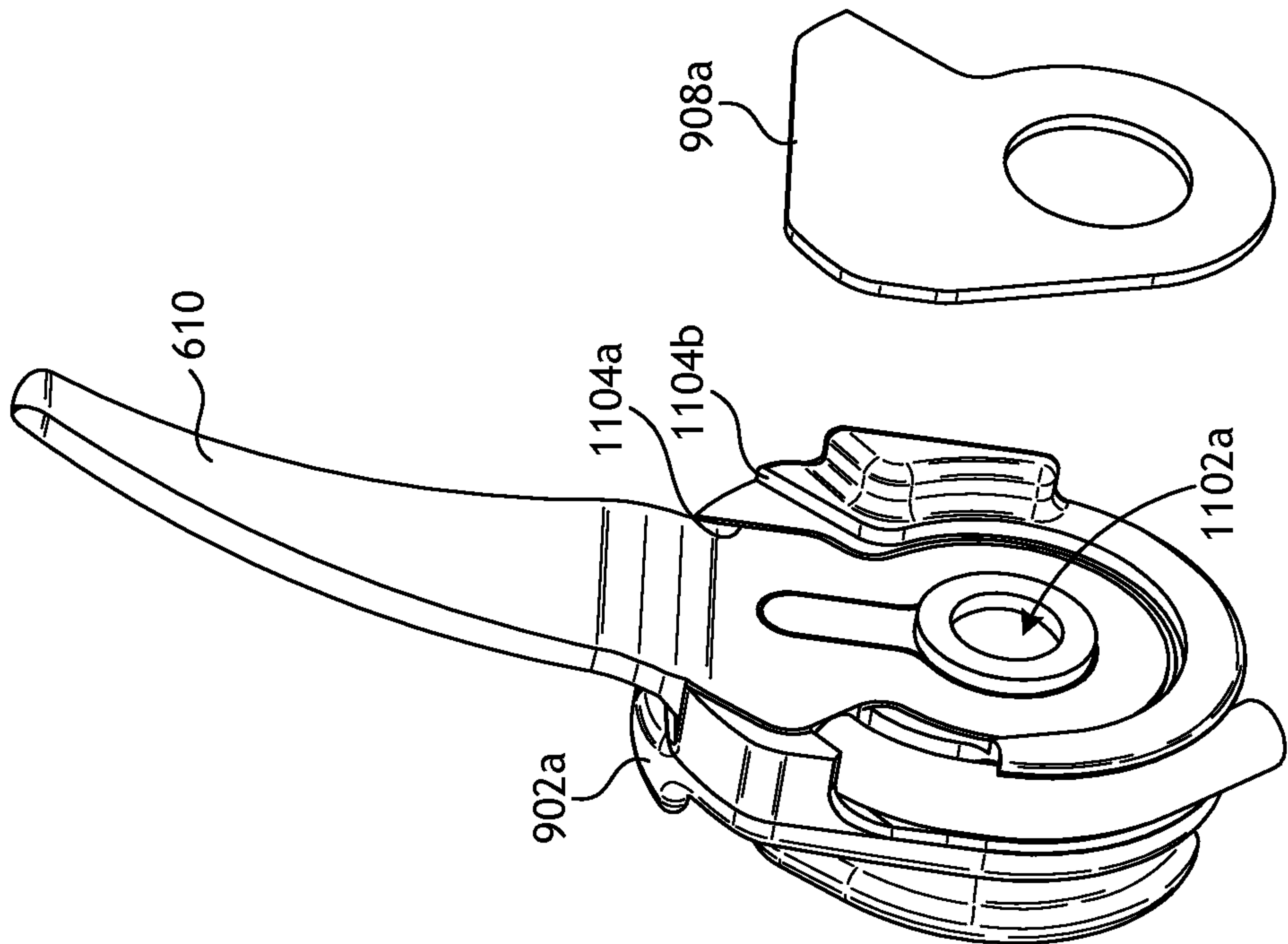


FIG. 11A

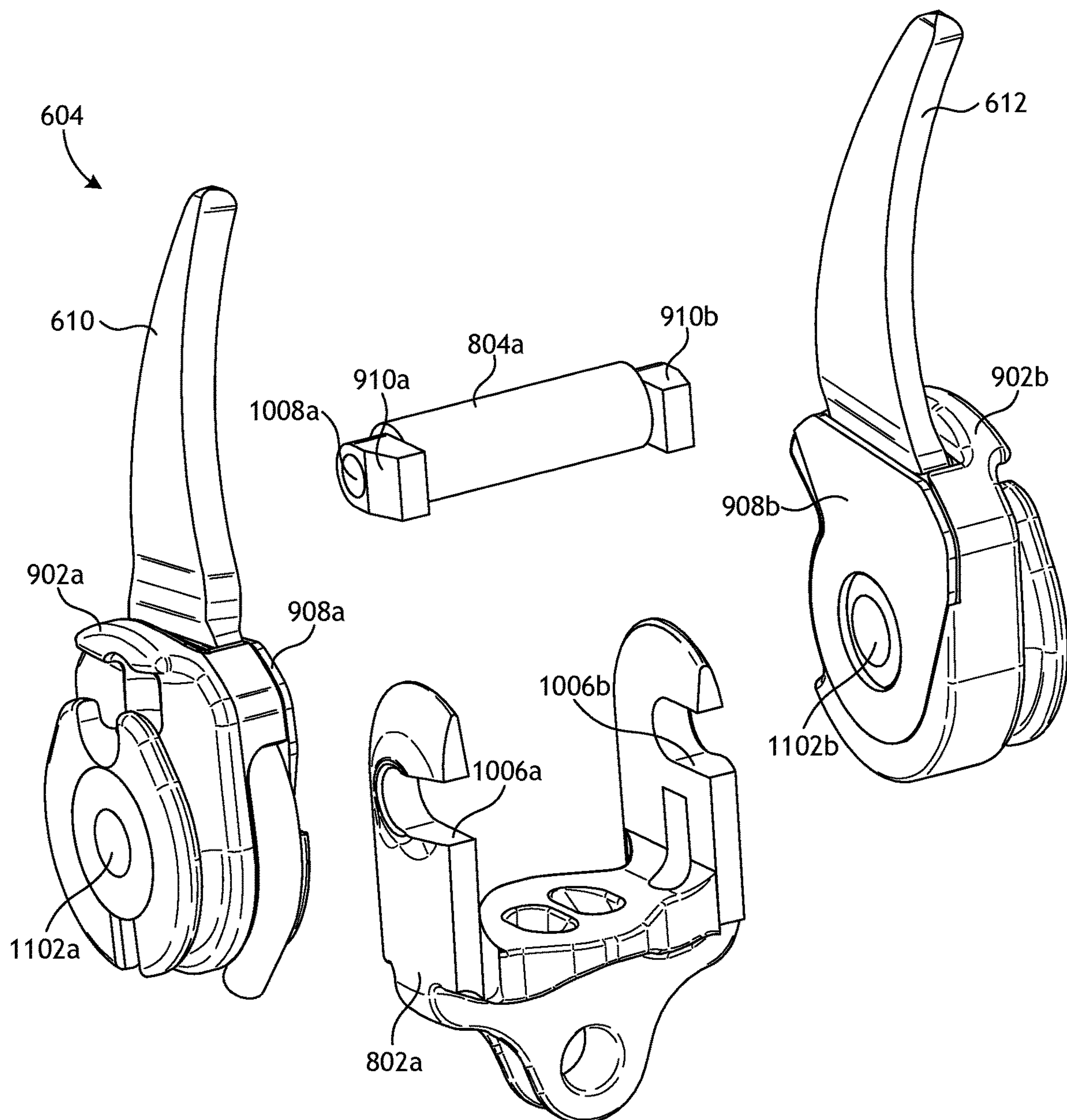


FIG. 12

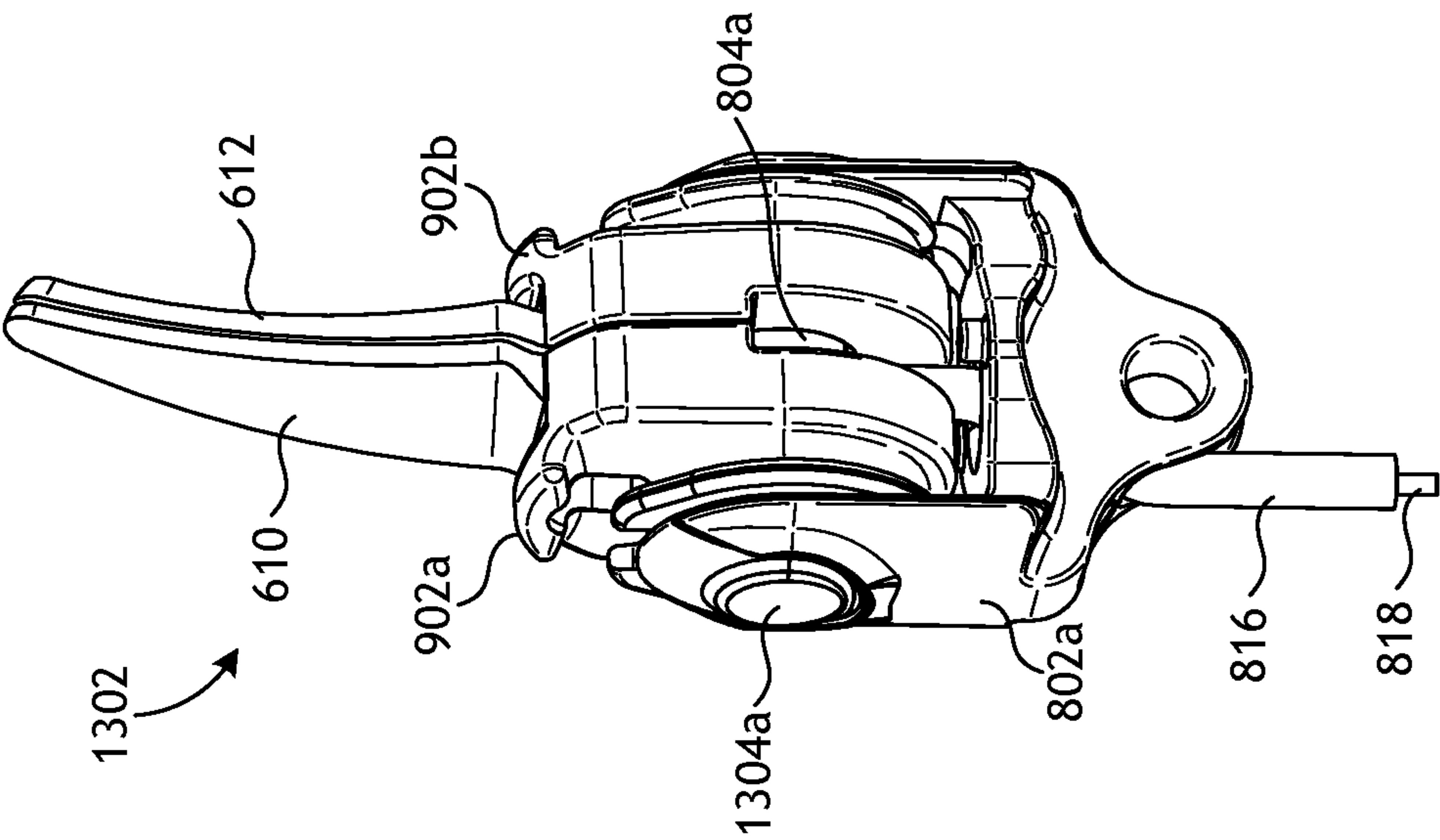


FIG. 13

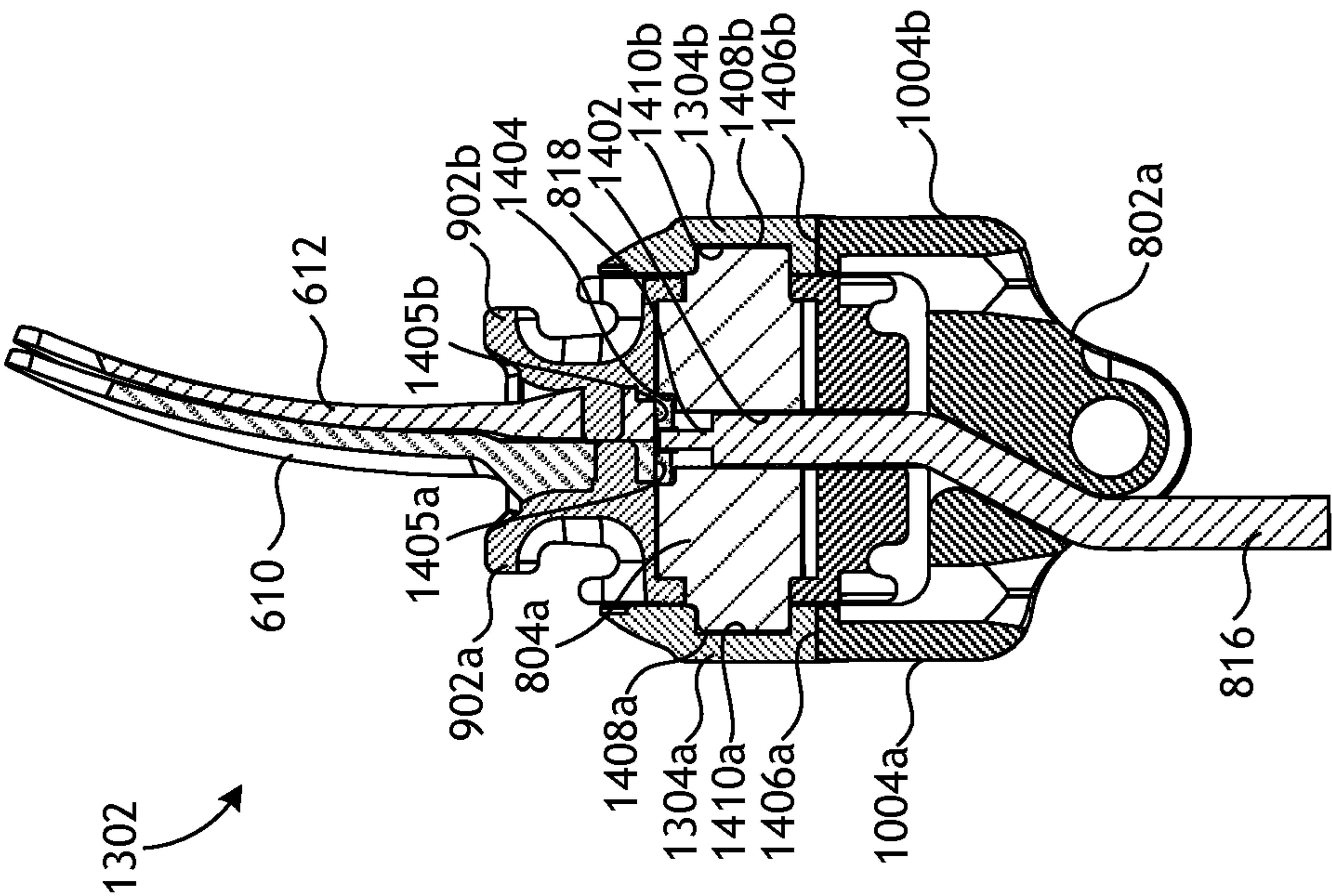


FIG. 14

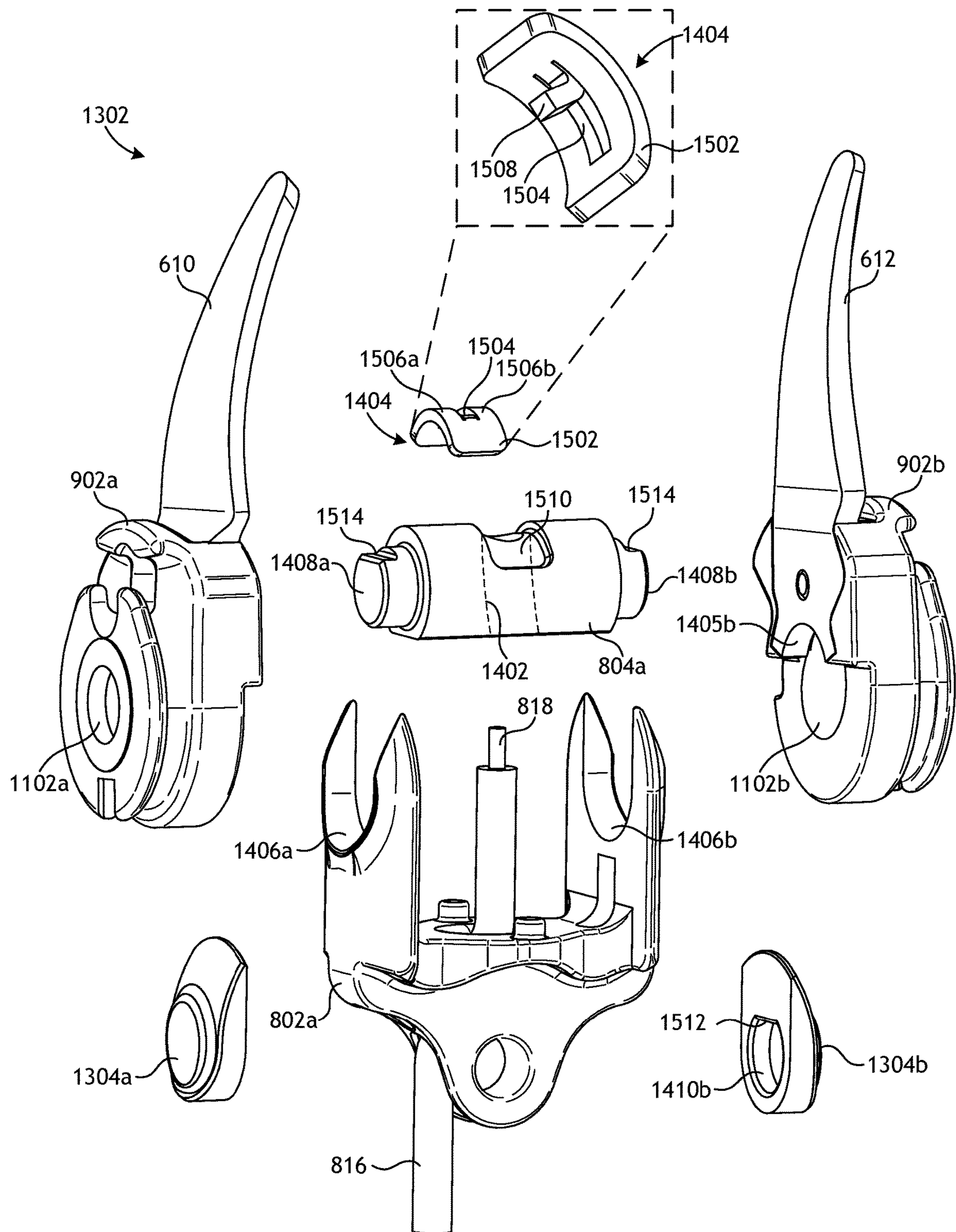


FIG. 15

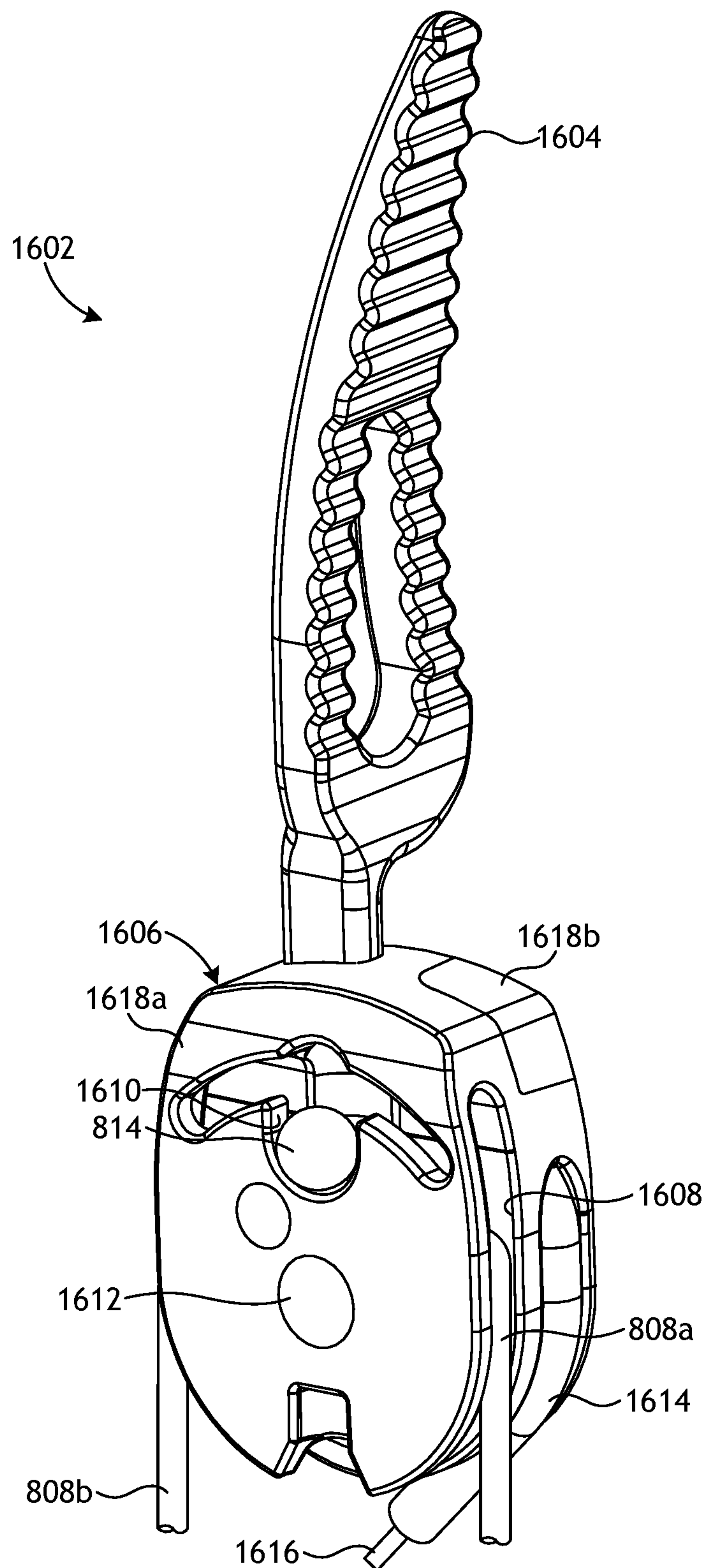
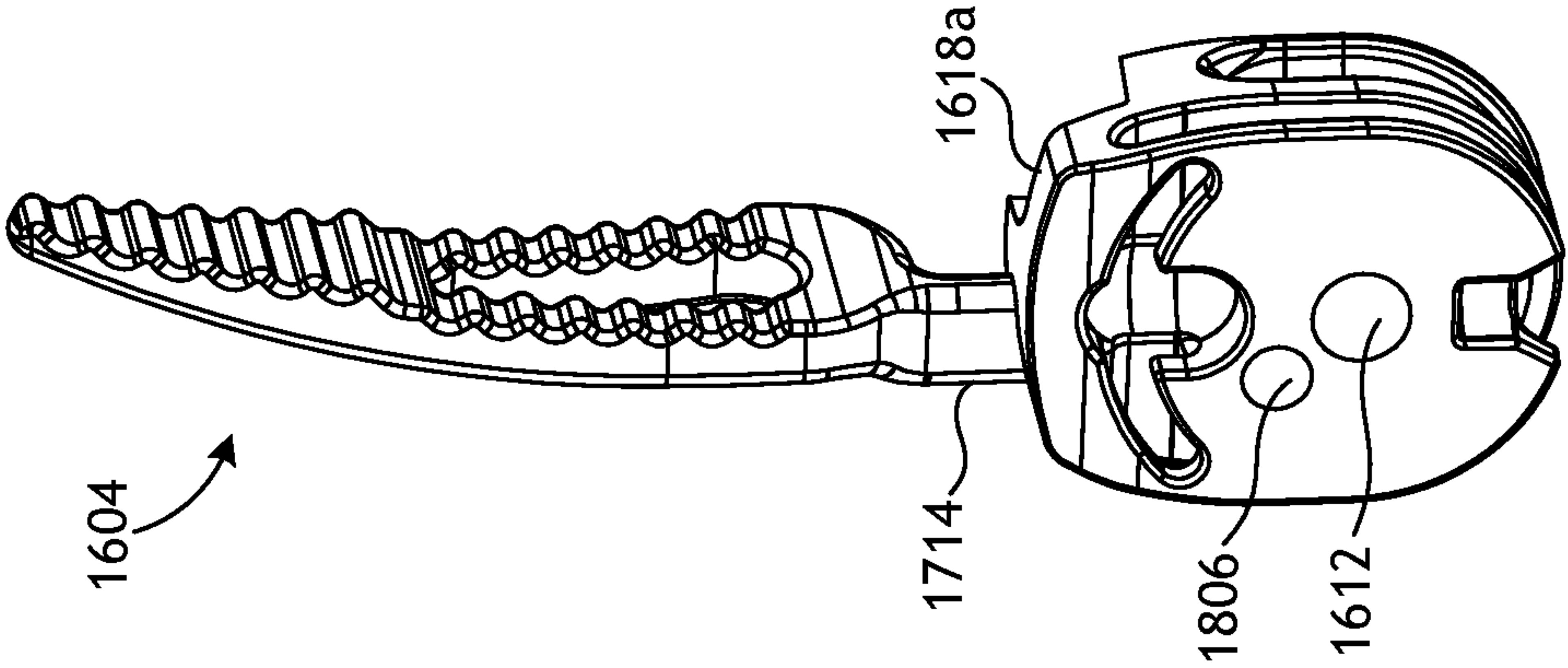
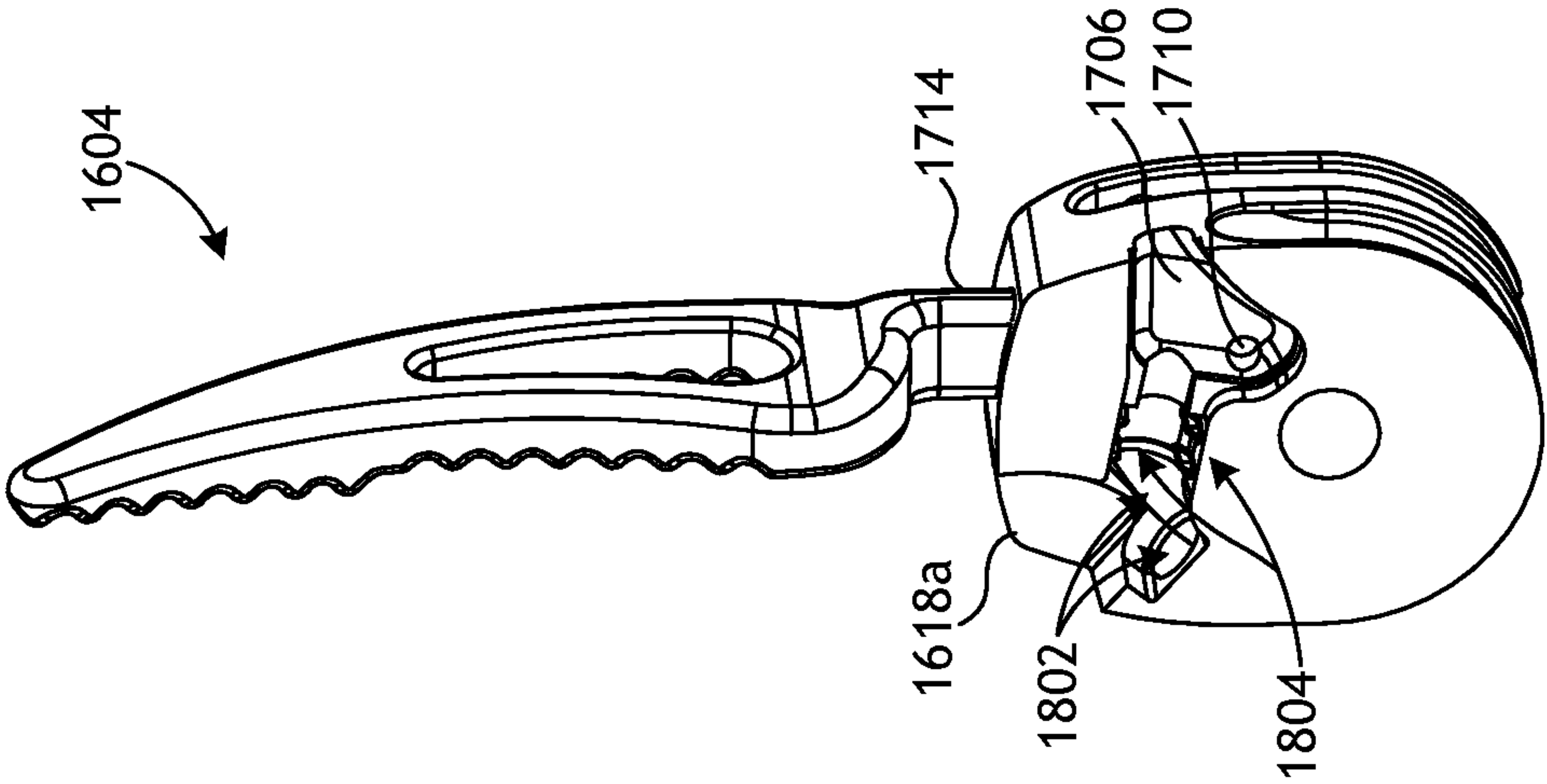
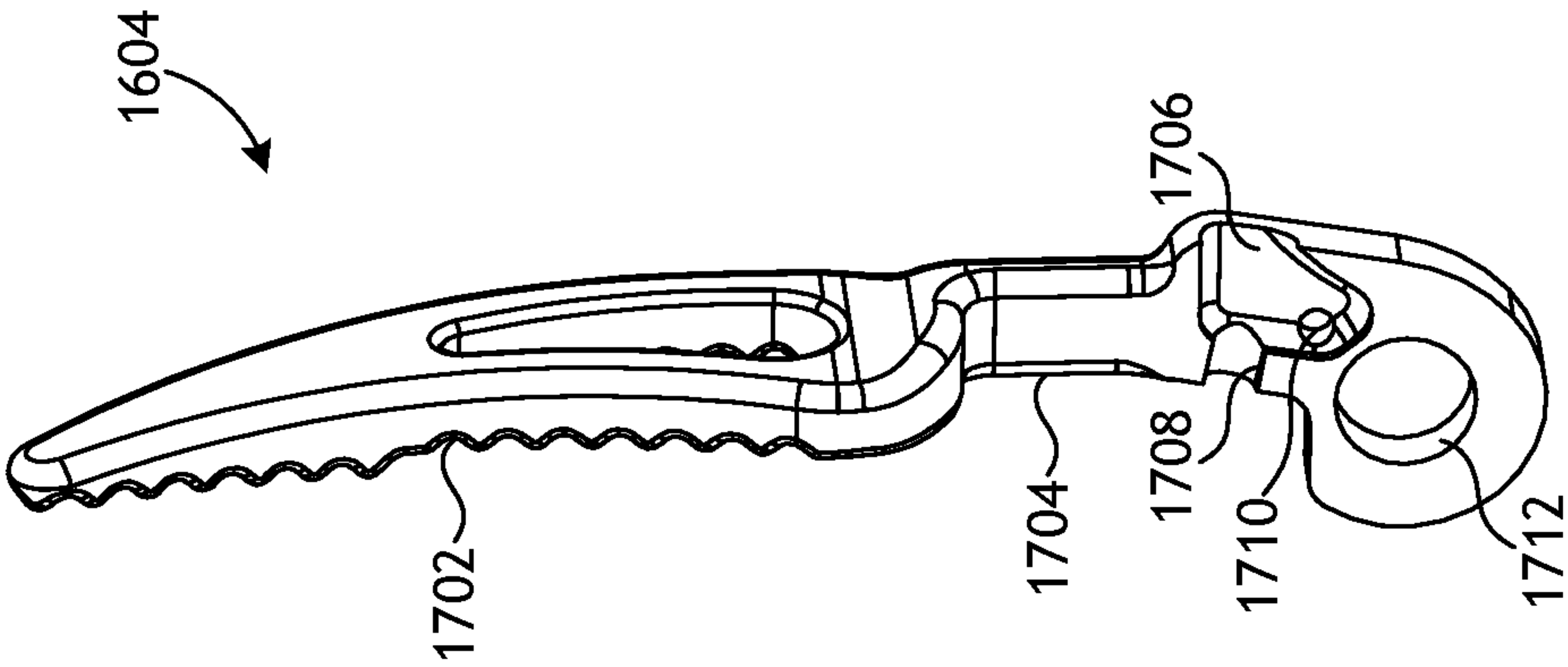


FIG. 16



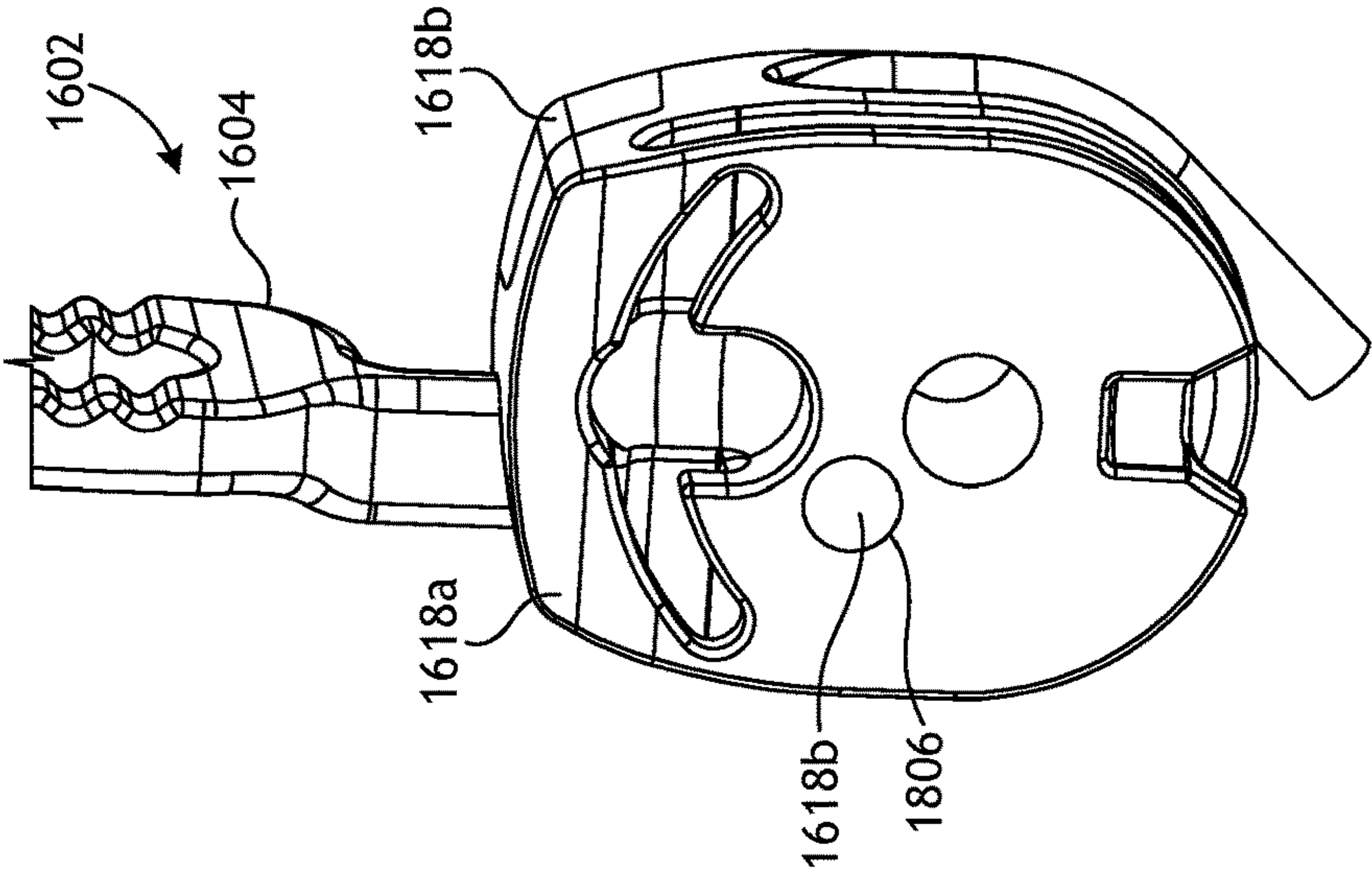


FIG. 20B

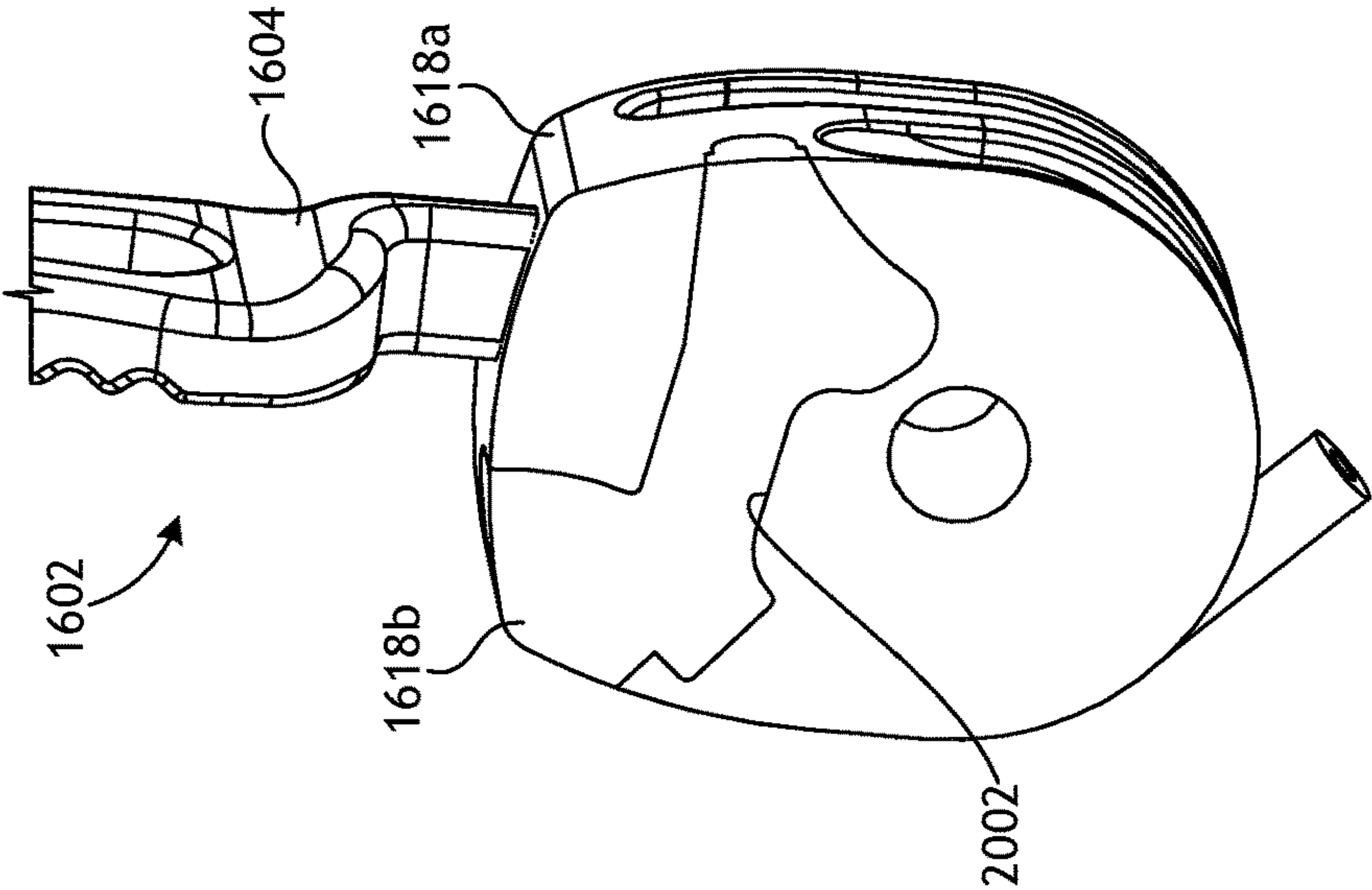


FIG. 20A

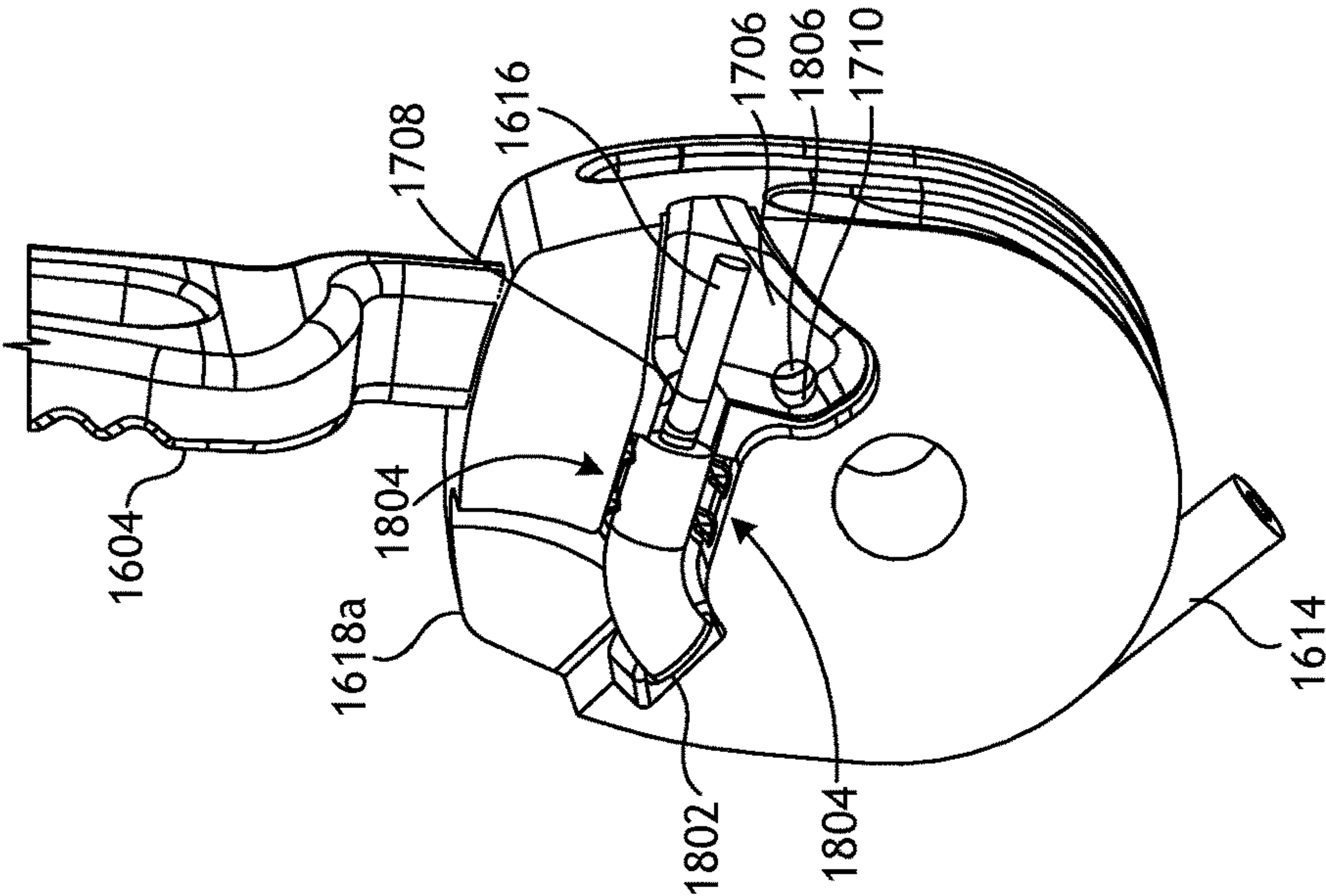


FIG. 19

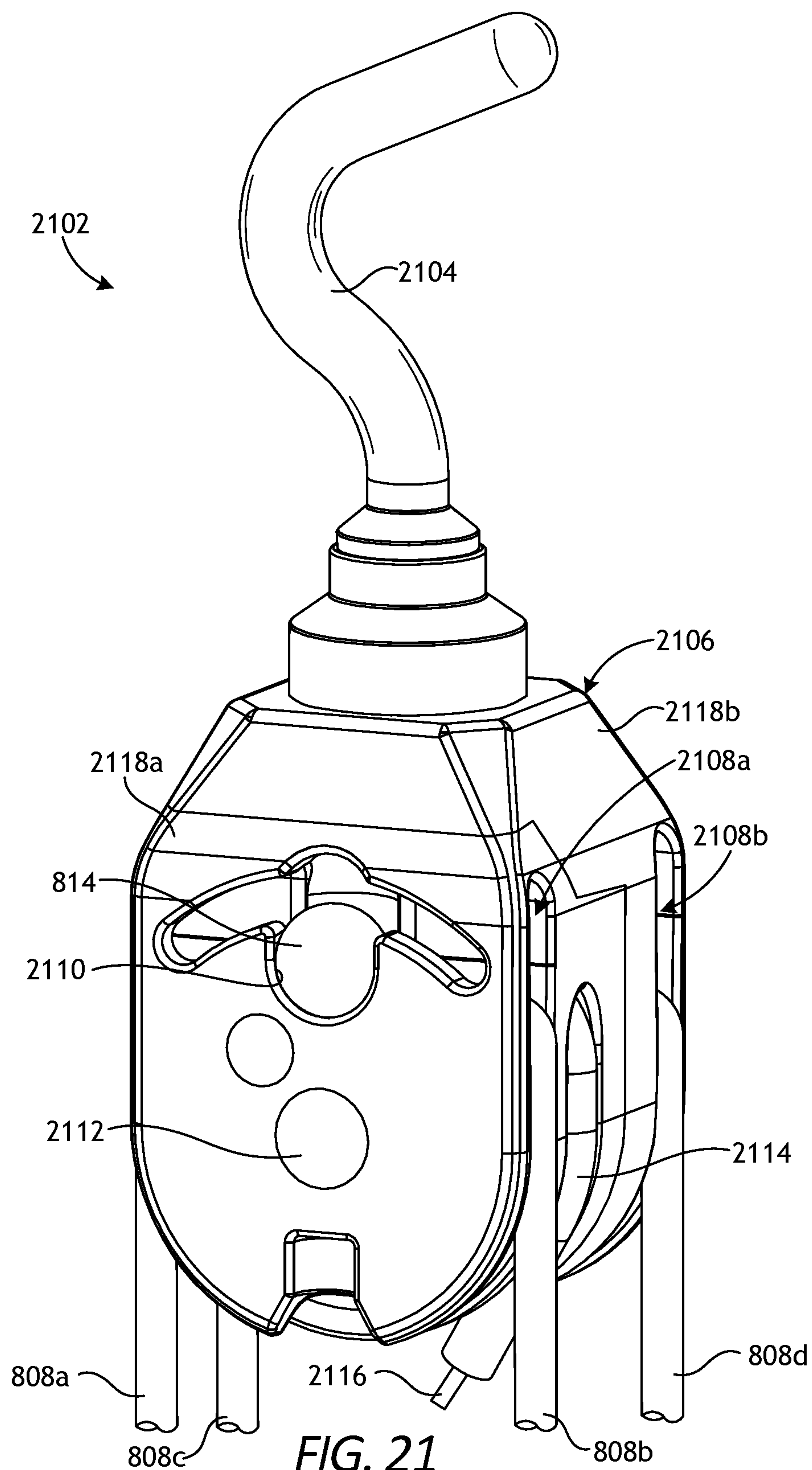


FIG. 21

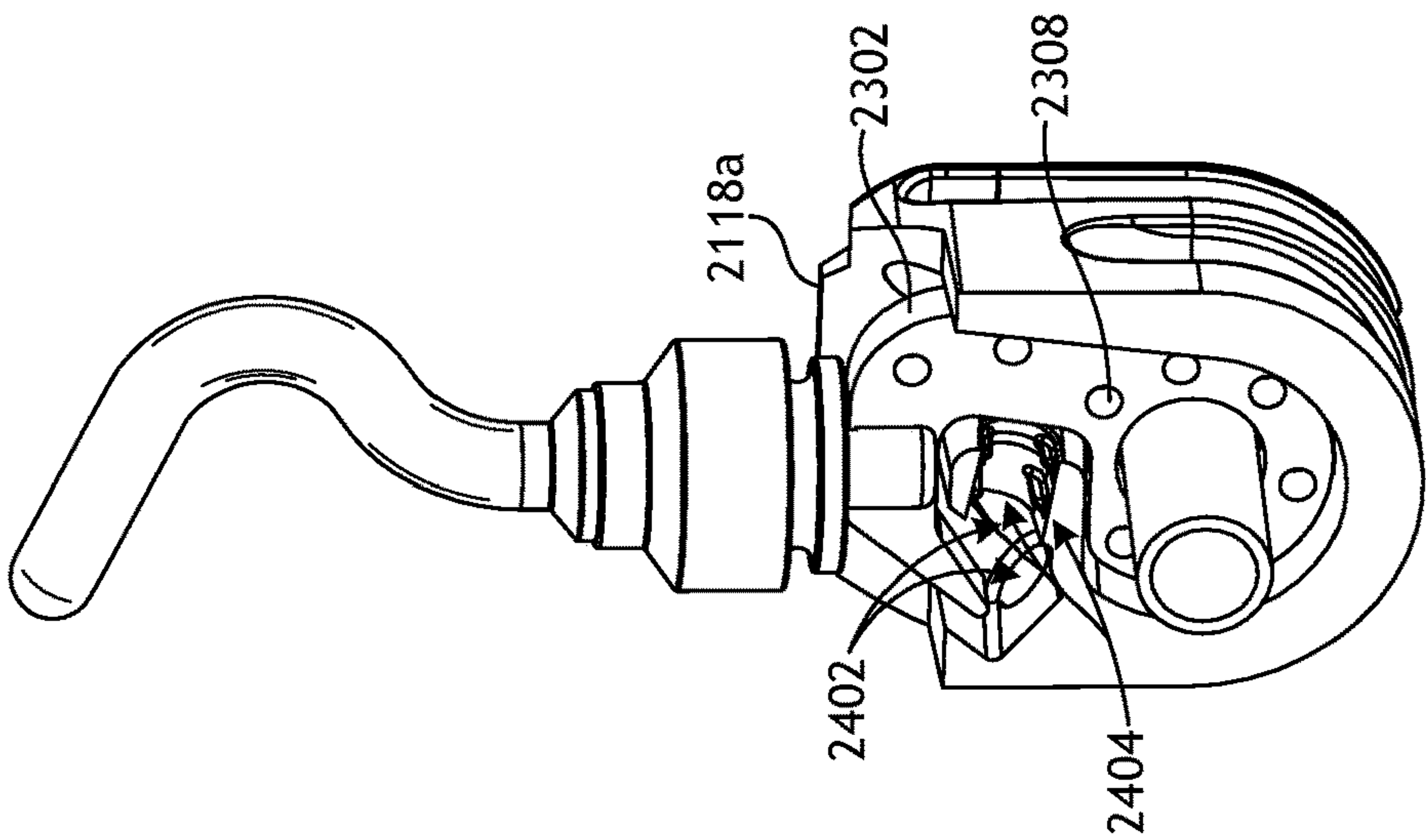


FIG. 24A

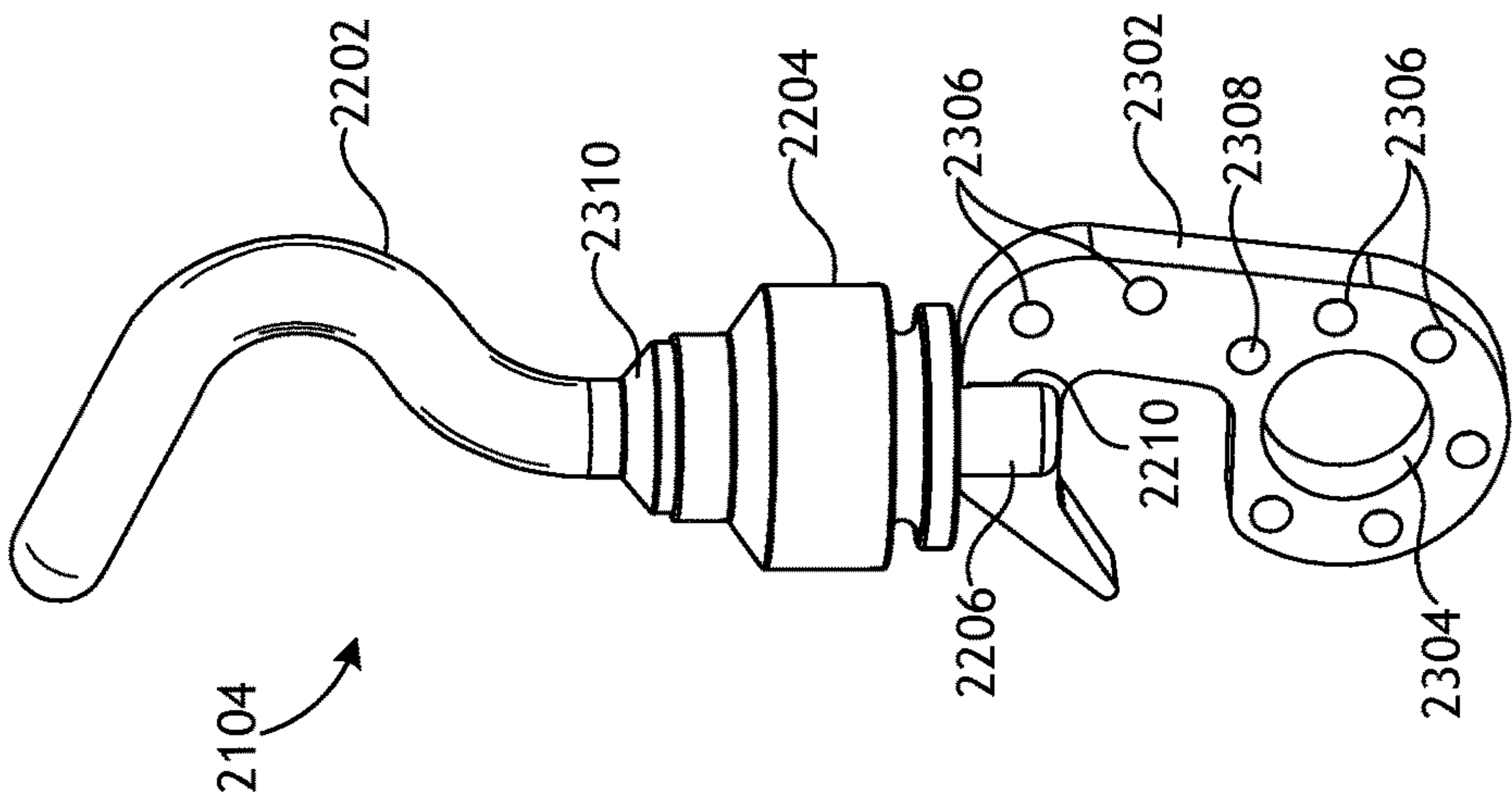


FIG. 23

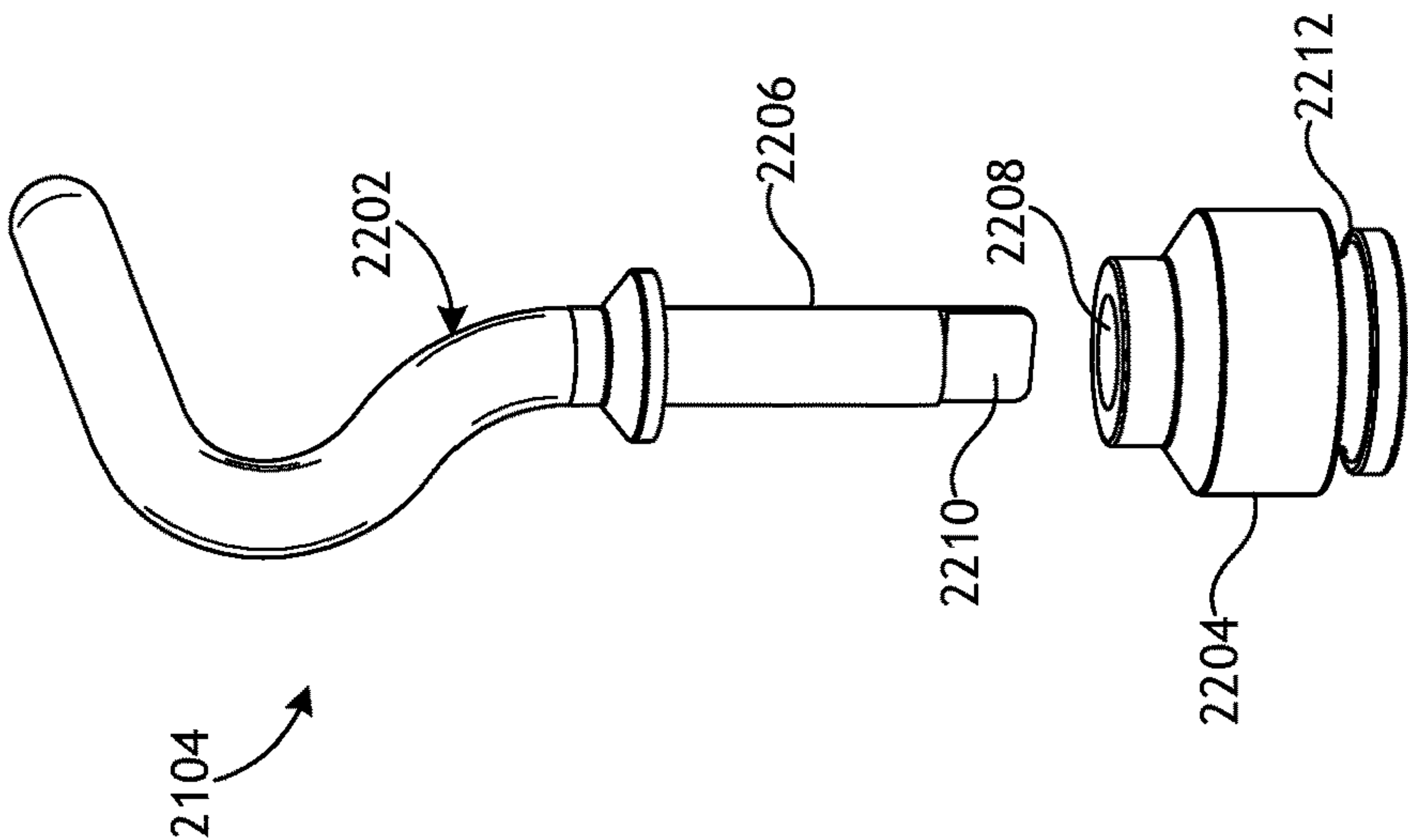


FIG. 22

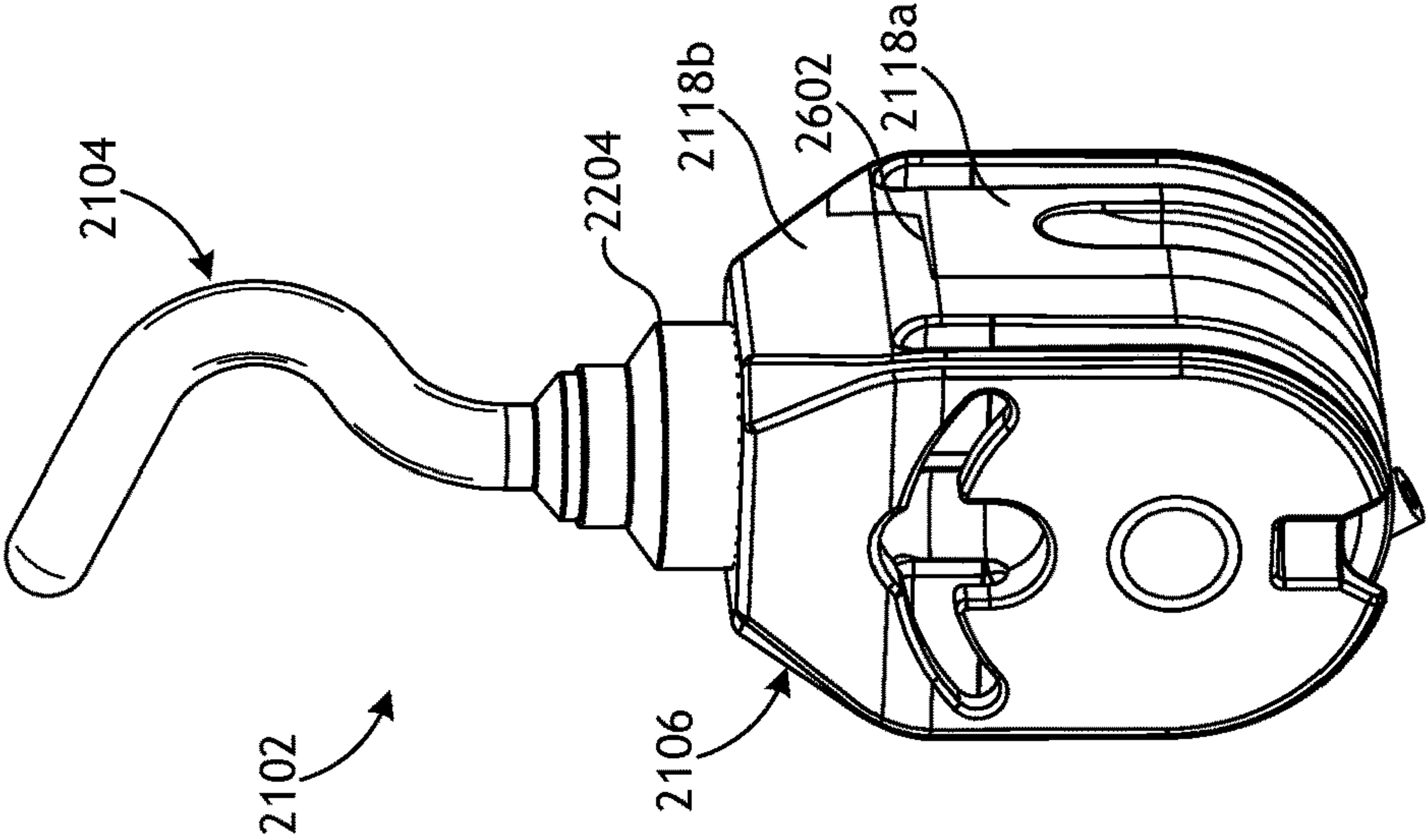


FIG. 26A

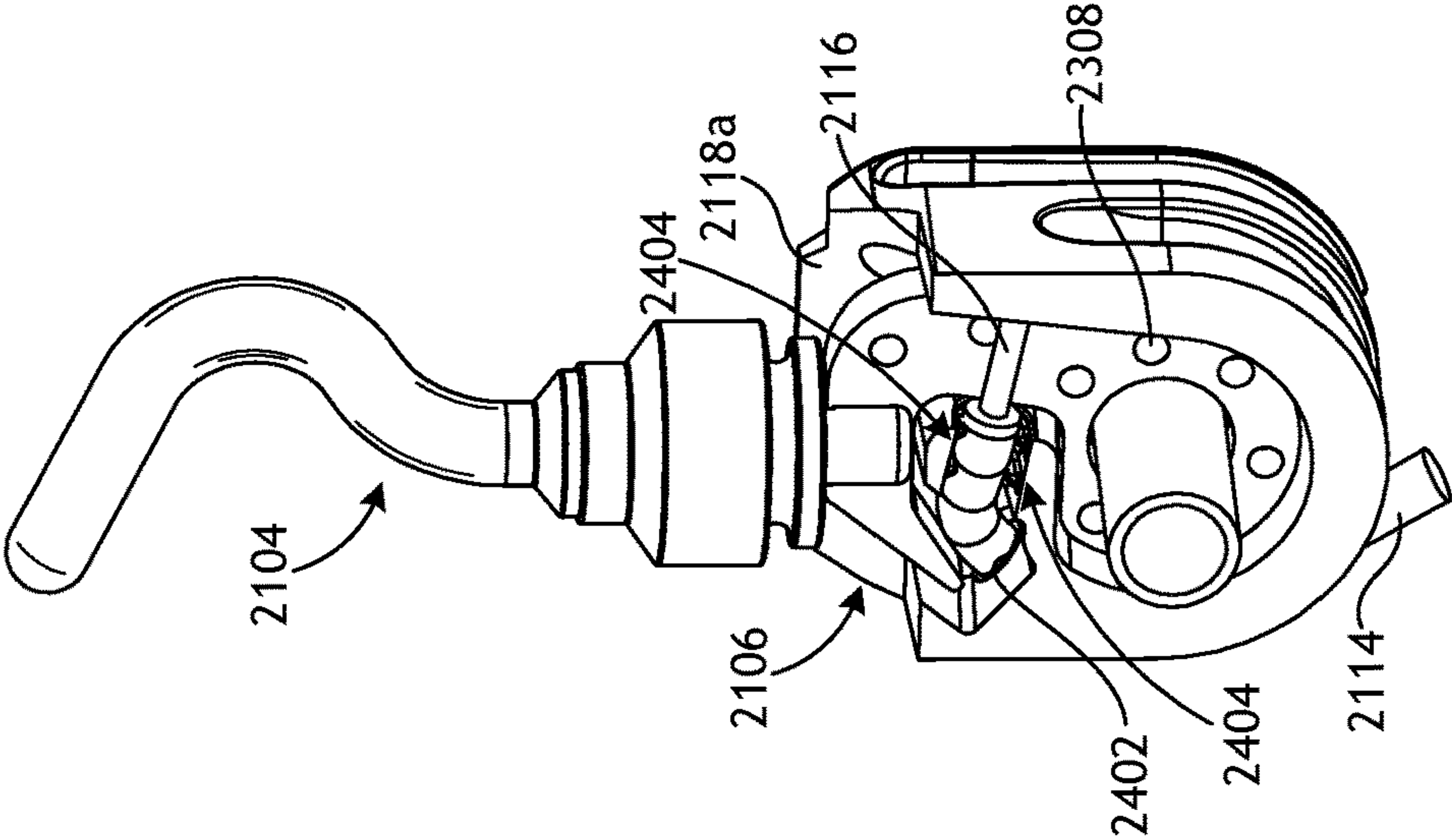


FIG. 25

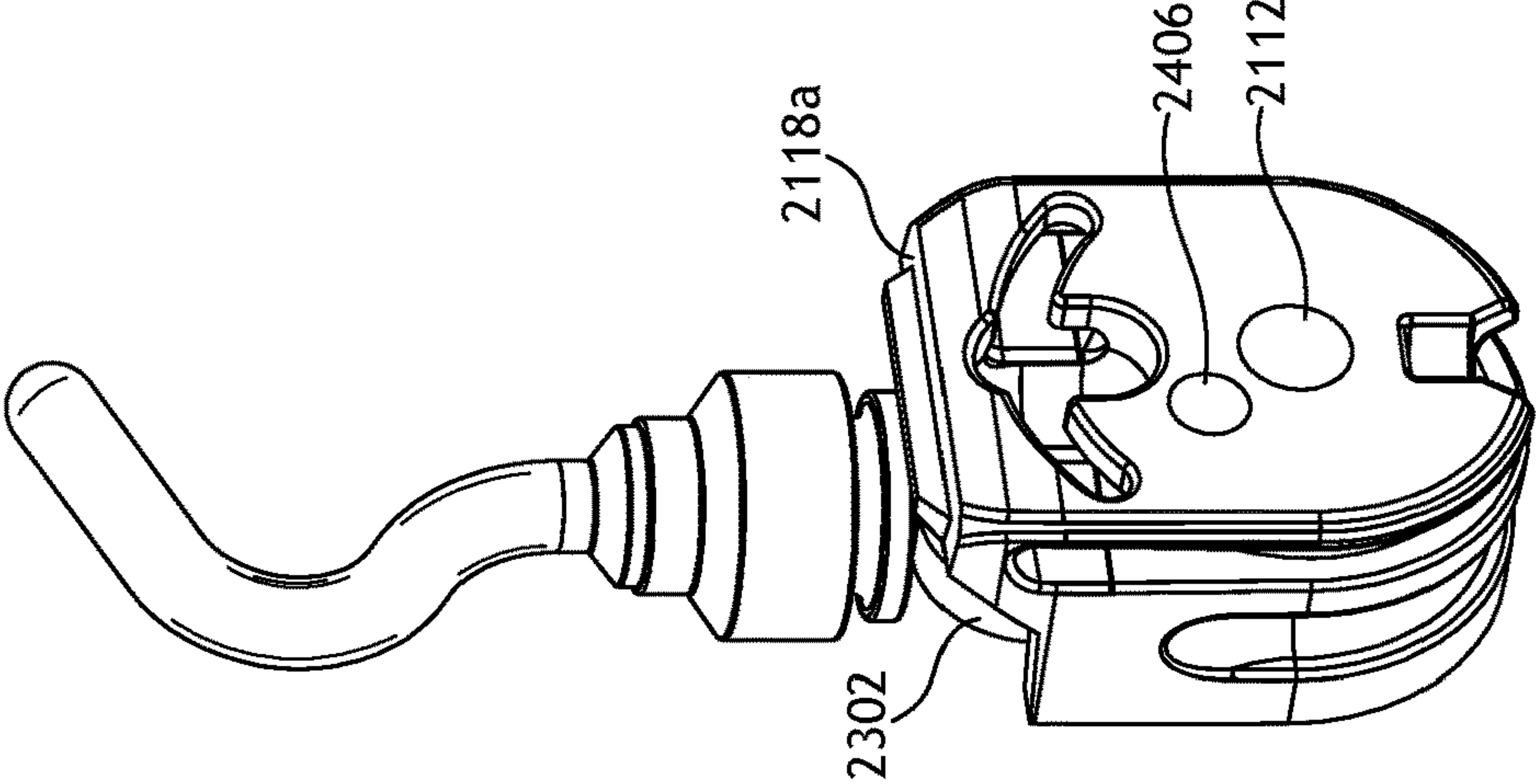


FIG. 24B

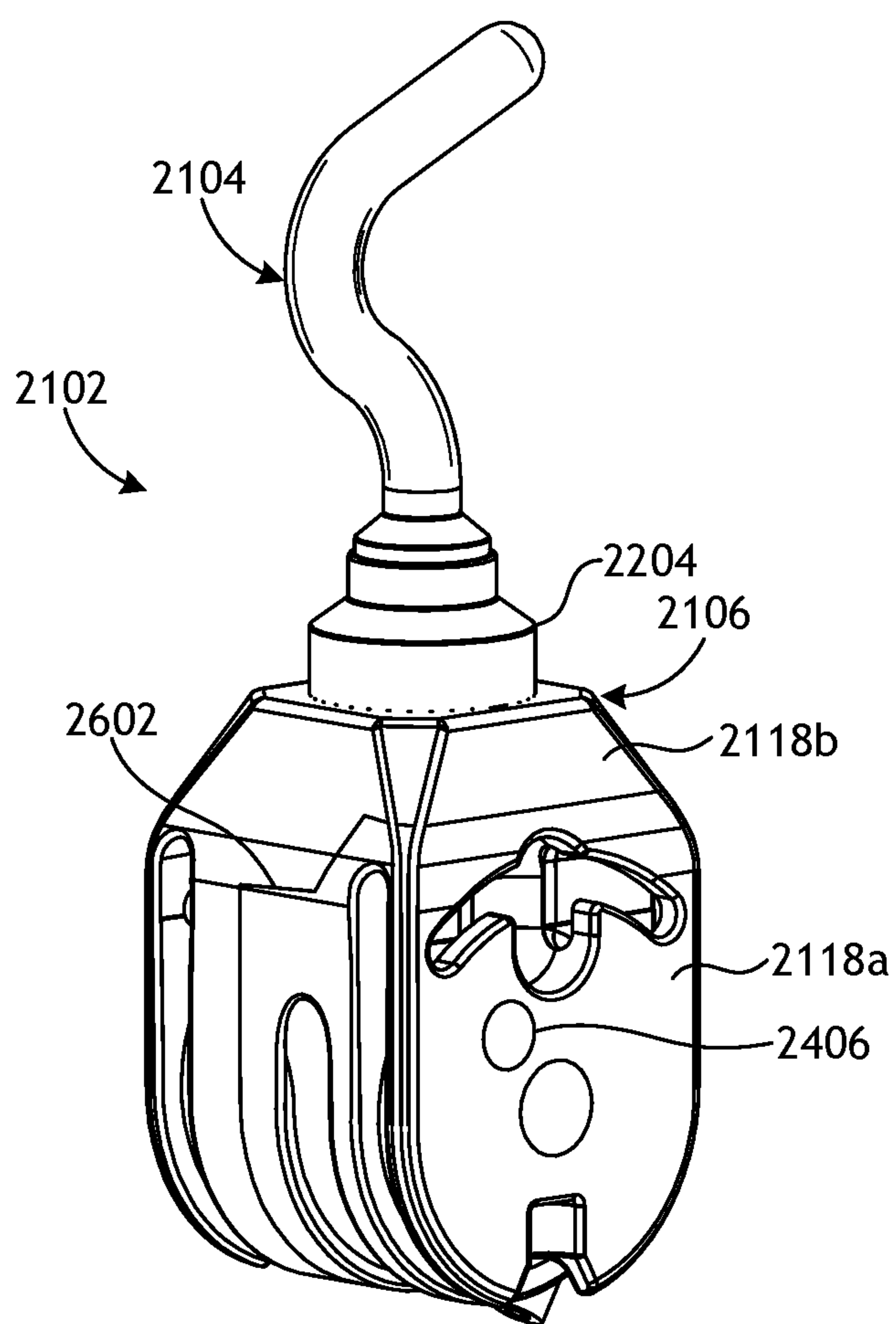


FIG. 26B

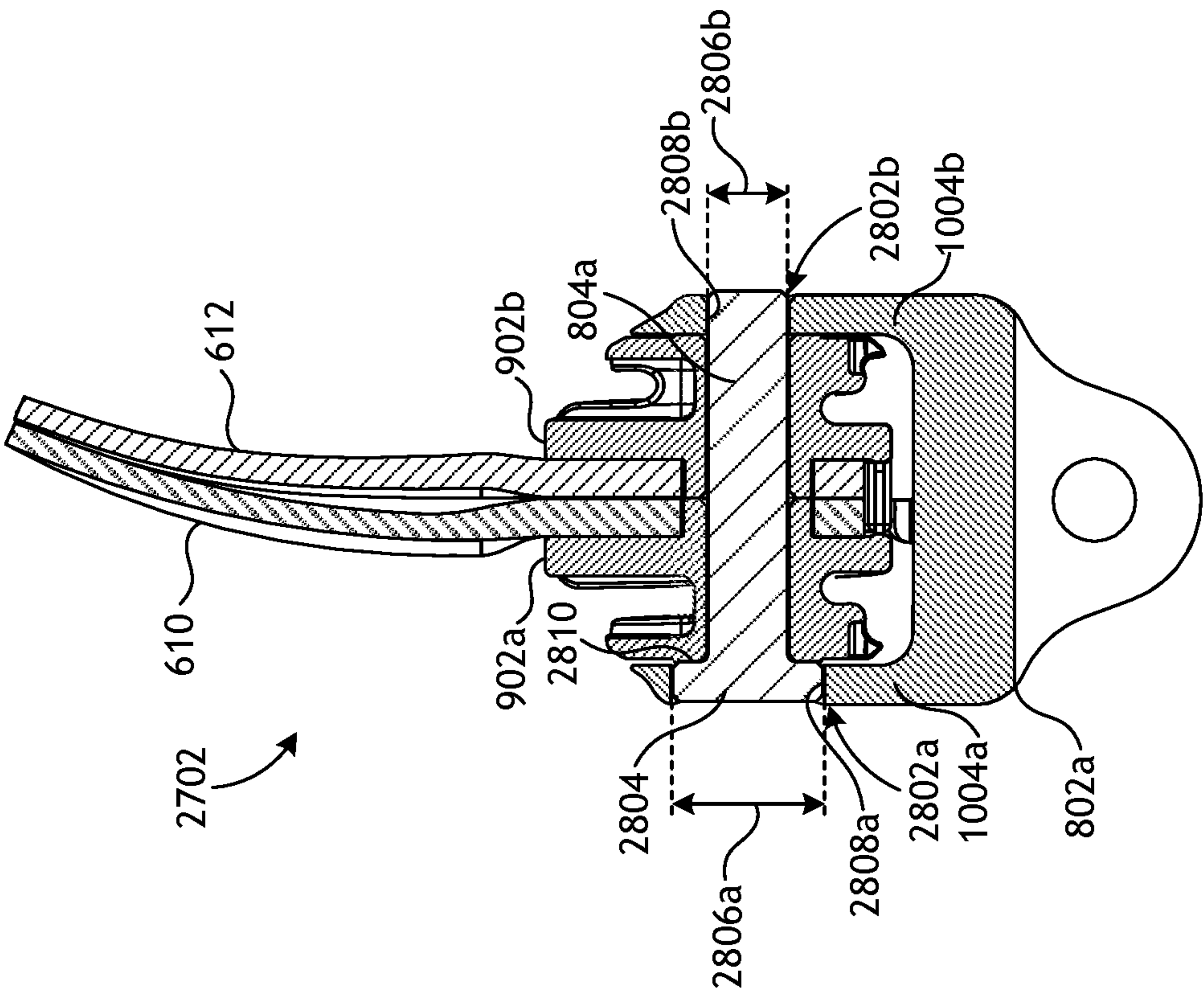


FIG. 27

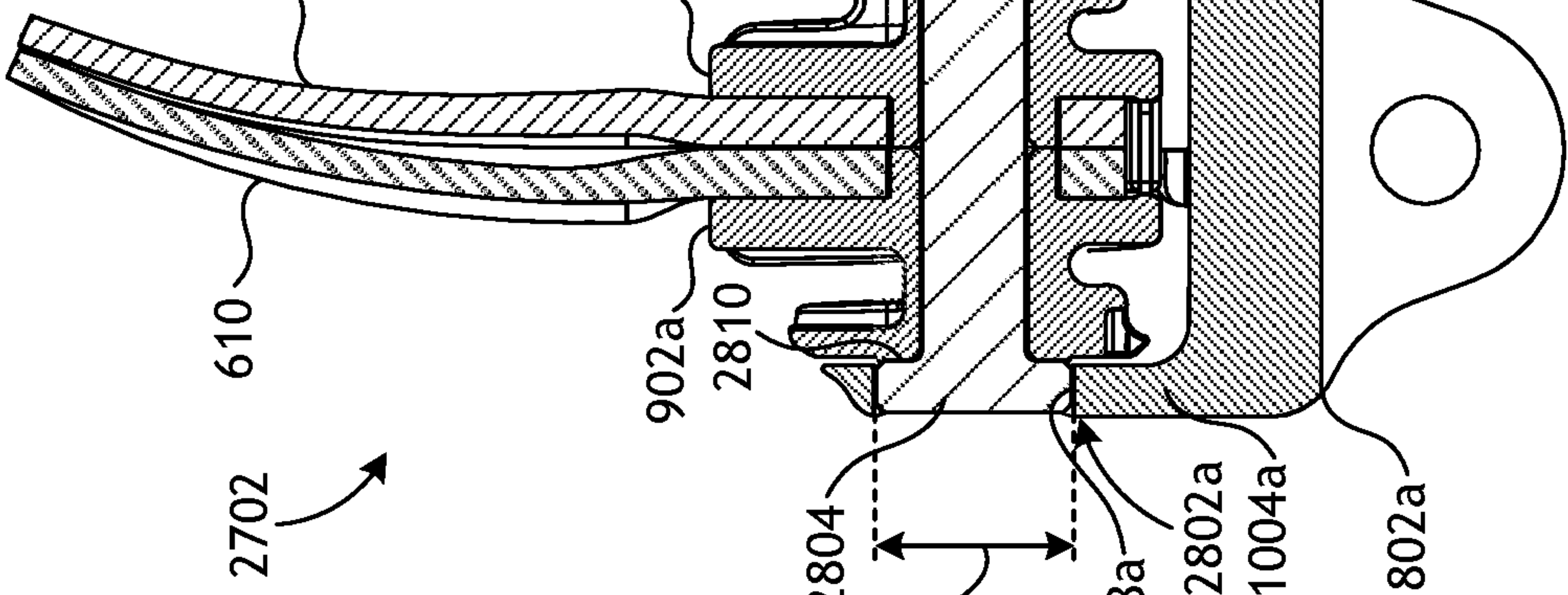


FIG. 28

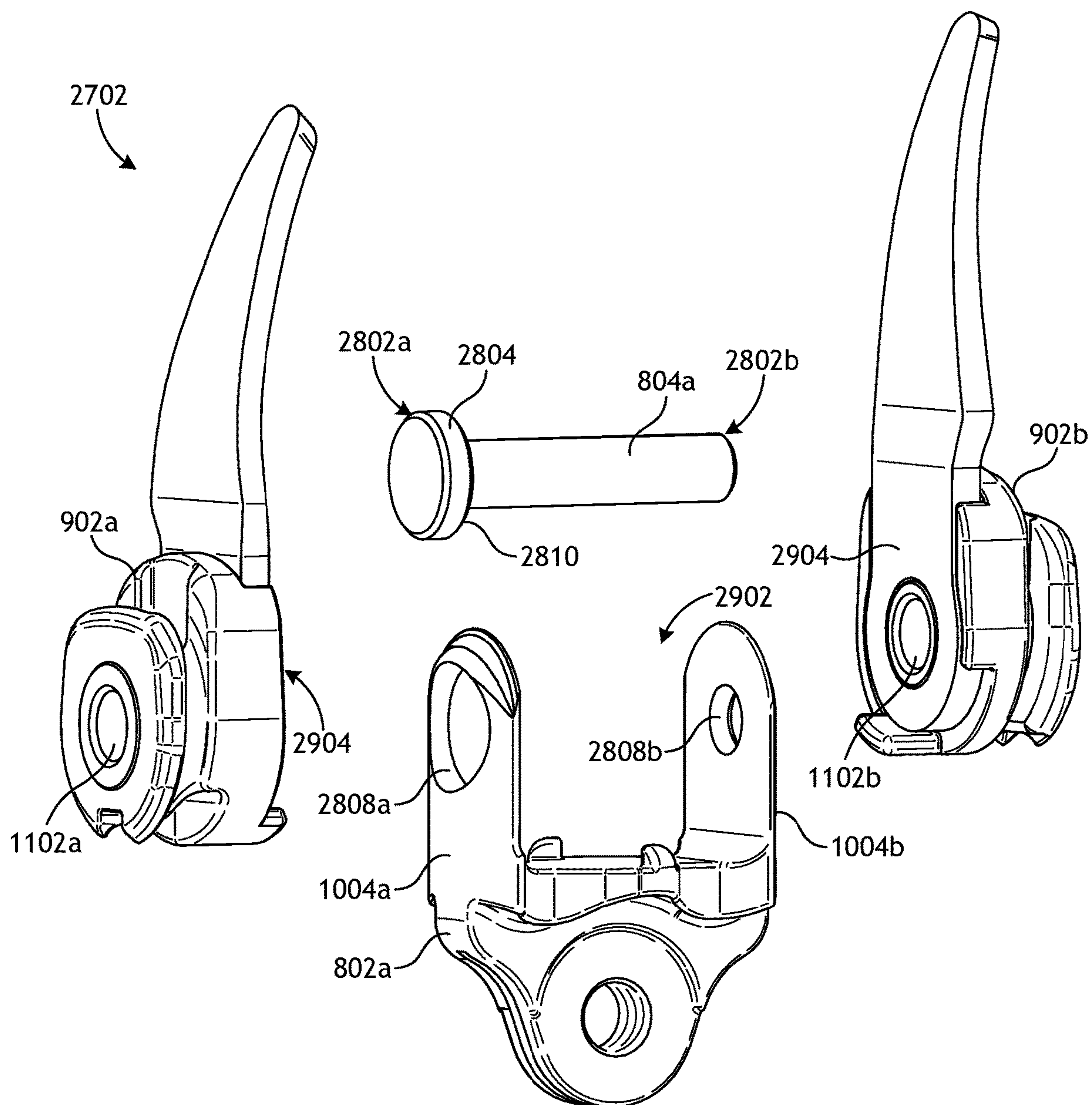


FIG. 29

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ELECTRICAL ISOLATION OF
ELECTROSURGICAL INSTRUMENTS

BACKGROUND

Minimally invasive surgical (MIS) instruments are often preferred over traditional open surgical devices due to reduced post-operative recovery time and minimal scarring. Laparoscopic surgery is one type of MIS procedure in which one or more small incisions are formed in the abdomen of a patient and a trocar is inserted through the incision to form a pathway that provides access to the abdominal cavity. Through the trocar, a variety of instruments and surgical tools can be introduced into the abdominal cavity. The trocar also helps facilitate insufflation to elevate the abdominal wall above the organs. The instruments and tools introduced into the abdominal cavity via the trocar can be used to engage and/or treat tissue in a number of ways to achieve a diagnostic or therapeutic effect.

Various robotic systems have recently been developed to assist in MIS procedures. Robotic systems can allow for more intuitive hand movements by maintaining natural eye-hand axis. Robotic systems can also allow for more degrees of freedom in movement by including a “wrist” joint that creates a more natural hand-like articulation. The instrument’s end effector can be articulated (moved) using a cable driven motion system having one or more drive cables that extend through the wrist joint. A user (e.g., a surgeon) is able to remotely operate an instrument’s end effector by grasping and manipulating in space one or more controllers that communicate with a tool driver coupled to the surgical instrument. User inputs are processed by a computer system incorporated into the robotic surgical system and the tool driver responds by actuating the cable driven motion system and, more particularly, the drive cables. Moving the drive cables articulates the end effector to desired positions and configurations.

Some surgical tools, commonly referred to as electrosurgical instruments, are electrically energized. An electrosurgical instrument has a distally mounted end effector that includes one or more electrodes. When supplied with electrical energy, the end effector electrodes are able to generate heat sufficient to cut, cauterize, and/or seal tissue.

Electrosurgical instruments can be configured for bipolar or monopolar operation. In bipolar operation, current is introduced into and returned from the tissue by active and return electrodes, respectively, of the end effector. Electrical current in bipolar operation is not required to travel long distances through the patient before returning to the return electrode. Consequently, the amount of electrical current required is minimal, which greatly reduces the risk of accidental ablations and/or burns. In addition, the two electrodes are closely spaced and within the surgeon’s field of view, which further reduces the risk of unintended ablations and burns.

In monopolar operation, current is introduced into the tissue by an active (or source) end effector electrode and returned through a return electrode (e.g., a grounding pad) separately located on a patient’s body. Monopolar electrosurgical instruments facilitate several surgical functions, such as cutting tissue, coagulating tissue to stop bleeding, or concurrently cutting and coagulating tissue. The surgeon can apply a current whenever the conductive portion of the instrument is in electrical proximity with the patient, per-

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mitting the surgeon to operate with monopolar electrosurgical instruments from many different angles.

BRIEF DESCRIPTION OF THE DRAWINGS

The following figures are included to illustrate certain aspects of the present disclosure, and should not be viewed as exclusive embodiments. The subject matter disclosed is capable of considerable modifications, alterations, combinations, and equivalents in form and function, without departing from the scope of this disclosure.

FIG. 1 is a block diagram of an example robotic surgical system that may incorporate some or all of the principles of the present disclosure.

FIG. 2 is an example embodiment of the master controller of FIG. 1 that may be used to operate a robotic arm slave cart.

FIG. 3 depicts an example embodiment of the robotic arm cart of FIG. 1 used to actuate a plurality of surgical instruments.

FIG. 4 is a side view schematic diagram of an example embodiment of the robotic manipulator of FIG. 3.

FIG. 5 is a perspective view of an alternative example robotic manipulator.

FIG. 6 is a side view of an example surgical tool that may incorporate some or all of the principles of the present disclosure.

FIG. 7 illustrates potential degrees of freedom in which the wrist of FIG. 1 may be able to articulate (pivot).

FIG. 8 is an enlarged isometric view of the distal end of the surgical tool of FIG. 1.

FIG. 9 is an enlarged view of the end effector 604 of FIG. 8.

FIG. 10A is an isometric view of the end effector of FIG. 9 without the first jaw holder.

FIG. 10B is an isometric view of the end effector of FIG. 9 without the second jaw holder.

FIG. 11A is a partially exploded view of the first jaw holder and corresponding first spacer.

FIG. 11B is a partially exploded view of the second jaw holder and corresponding second spacer.

FIG. 12 is an isometric exploded view of the end effector of FIG. 8.

FIG. 13 is an enlarged view of another example end effector that might be used with the surgical tool of FIG. 6.

The FIG. 14 is a cross-sectional front view of the end effector of FIG. 13.

FIG. 15 is an isometric exploded view of the end effector of FIG. 13.

FIG. 16 is an isometric view of a portion of another example end effector that might be used with the surgical tool of FIG. 6.

FIG. 17 is an isometric side view of the jaw of FIG. 16.

FIGS. 18A and 18B are front and back views, respectively, of the first portion of the jaw holder of FIG. 16 following a first overmold shot.

FIG. 19 depicts the electrical conductor received within the first portion of the jaw holder of FIG. 16.

FIGS. 20A and 20B are front and back views, respectively, of the end effector of FIG. 16 following a second overmold shot.

FIG. 21 is an isometric view of another example end effector, according to one or more embodiments.

FIG. 22 is an isometric side view of the jaw of FIG. 21.

FIG. 23 is another isometric side view of the jaw of FIG. 21.

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FIGS. 24A and 24B are front and back views, respectively, of the first portion of the jaw holder of FIG. 21 following a first assembly sequence.

FIG. 25 depicts the electrical conductor received within the first portion of the jaw holder 2106 of FIG. 21.

FIGS. 26A and 26B are front and back views, respectively, of the end effector of FIG. 21 following a second assembly sequence.

FIG. 27 is an enlarged isometric view of another example end effector that may be used with the surgical tool of FIG. 6.

FIG. 28 is a cross-sectional front view of the end effector of FIG. 27.

FIG. 29 is an exploded view of the end effector of FIG. 27.

DETAILED DESCRIPTION

The present disclosure is related to robotic surgical systems and, more particularly, to electrosurgical instruments having an end effector designed to insulate an electrical conductor from conductive materials that form part of the end effector.

Embodiments discussed herein describe electrosurgical instruments that use electrical energy to perform a variety of surgical procedures. End effectors that may be used with the electrosurgical instruments include a distal clevis, an axle mounted to the distal clevis, and a jaw holder rotatably mounted to the axle. A jaw may be secured to the jaw holder such that rotation of the jaw holder about the axle correspondingly rotates the jaw. An electrical conductor may supply electrical energy to the jaw via a supply conductor, and at least one of the jaw holder and the axle may be made of a non-conductive material that may prove advantageous in insulating the distal clevis from the electrical energy provided to the jaw.

FIGS. 1-5 illustrate the structure and operation of example robotic surgical systems and components thereof. FIG. 1 is a block diagram of an example robotic surgical system 100 that may incorporate some or all of the principles of the present disclosure. As illustrated, the system 100 can include at least one master controller 102a and at least one arm cart 104. The arm cart 104 may be mechanically and/or electrically coupled to one or more robotic arms 106, alternately referred to as “tool drivers”. Each robotic arm 106 may include and otherwise mount one or more surgical tools or instruments 108 for performing various surgical tasks on a patient 110. Operation of the arm cart 104, including the arms 106 and instruments 108 may be directed by a clinician 112a (e.g., a surgeon) from the master controller 102a.

In some embodiments, a second master controller 102b (shown in dashed lines) operated by a second clinician 112b may also direct operation of the arm cart 104 in conjunction with the first clinician 112a. In such embodiments, for example, each clinician 102a,b may control different arms 106 of the arm cart 104 or, in some cases, complete control of the arm cart 104 may be passed between the clinicians 102a,b. In some embodiments, additional arm carts (not shown) may be utilized on the patient 110, and these additional arm carts may be controlled by one or more of the master controllers 102a,b.

The arm cart(s) 104 and the master controllers 102a,b may be in communication with one another via a communications link 114, which may be any type of wired or wireless communications link configured to carry suitable types of signals (e.g., electrical, optical, infrared, etc.) according to any communications protocol. The communi-

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cations link 114 may be an actual physical link or it may be a logical link that uses one or more actual physical links. When the link is a logical link the type of physical link may be a data link, uplink, downlink, fiber optic link, point-to-point link, for example, as is well known in the computer networking art to refer to the communications facilities that connect nodes of a network. Example implementations of robotic surgical systems, such as the system 100, are disclosed in U.S. Pat. No. 7,524,320, the contents of which are incorporated herein by reference. The various particularities of such devices will not be described in detail herein beyond that which may be necessary to understand various embodiments and forms of the various embodiments of robotic surgery apparatus, systems, and methods disclosed herein.

FIG. 2 is an example embodiment of the master controller 102a that may be used to operate a robotic arm slave cart, such as the arm cart 104 of FIG. 1. The master controller 102a and its associated arm cart 104, as well as their respective components and control systems, are collectively referred to herein as a “robotic surgical system.” Examples of such systems and devices are disclosed in U.S. Pat. No. 7,524,320 and, therefore, will not be described in detail herein beyond that which may be necessary to understand various embodiments and forms of the present invention.

The master controller 102a generally includes one or more controllers 202 that can be grasped by a surgeon (e.g., the clinician 112a of FIG. 1) and manipulated in space while the surgeon views the procedure via a stereo display 204. The master controllers 202 generally comprise manual input devices designed to move in multiple degrees of freedom, and which often further have an actuatable handle for actuating a surgical instrument (e.g., the surgical instrument (s) 108 of FIG. 1), for example, for opening and closing opposing jaws, applying an electrical potential (current) to an electrode, or the like.

In the illustrated example, the master controller 102a further includes an optional feedback meter 206 viewable by the surgeon via the display 204 to provide the surgeon with a visual indication of the amount of force being applied to the surgical instrument (i.e., a cutting instrument or dynamic clamping member). Other sensor arrangements may be employed to provide the master controller 102a with an indication of other surgical instrument metrics, such as whether a staple cartridge has been loaded into an end effector or whether an anvil has been moved to a closed position prior to firing, for example.

FIG. 3 depicts an example embodiment of the robotic arm cart 104 used to actuate a plurality of surgical instruments 108, alternately referred to as “surgical tools.” Various robotic surgery systems and methods employing master controller and robotic arm cart arrangements are described in U.S. Pat. No. 6,132,368, the contents of which are hereby incorporated by reference. As illustrated, the robotic arm cart 104 may include a base 302 that supports three surgical instruments 108, and the surgical instruments 108 are each supported by a series of manually articulatable linkages, generally referred to as set-up joints 304, and a robotic manipulator 306. These structures are herein illustrated with protective covers extending over much of the robotic linkage. These protective covers may be optional, and may be limited in size or entirely eliminated in some embodiments to minimize the inertia that is encountered by the servo mechanisms used to manipulate such devices, to limit the volume of moving components so as to avoid collisions, and to limit the overall weight of the cart 104.

The cart 104 will generally have dimensions suitable for transporting the cart 104 between operating rooms. The cart

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104 may be configured to fit through standard operating room doors and onto standard hospital elevators. In some embodiments, the cart 104 may include a wheel system (or other transportation system) that allows the cart 104 to be positioned adjacent an operating table by a single attendant. In various embodiments, an automated reloading system including a base portion may be strategically located within a work envelope 308 of the robotic arm cart 104.

FIG. 4 is a side view schematic diagram of an example embodiment of the robotic manipulator 306. As illustrated, the robotic manipulator 306 may include linkage 402 that constrains movement of the surgical instrument 108 coupled thereto. The linkage 402 includes rigid links coupled by rotational joints in a parallelogram arrangement so that the surgical instrument 108 rotates around a point 404 in space.

The parallelogram arrangement constrains rotation to pivoting about a “pitch axis” that extends axis through the point 404, as indicated by a pitch arrow 406a. The links supporting the parallelogram linkage 402 are pivotally mounted to set-up joints 304 (FIG. 3) so that the surgical instrument 108 further rotates about a second axis 406b, referred to as the “yaw axis.” The pitch axis and the yaw axis 406b intersect at a remote center 408, which is aligned along a shaft 410 of the surgical instrument 108.

The surgical instrument 108 may have further degrees of driven freedom as supported by the robotic manipulator 306, including sliding motion of the surgical instrument 108 along a longitudinal tool axis “LT-LT”. As the surgical instrument 108 slides (translates) along the longitudinal tool axis LT-LT relative to the tool driver 306 (arrow 412), the remote center 408 remains fixed relative to a base 414 of the tool driver 306. Hence, the entire tool driver 306 is generally moved to re-position the remote center 408.

The linkage 402 of the tool driver 306 is driven by a series of motors 416. These motors 416 actively move the linkage 402 in response to commands from a processor of a control system. The motors 416 may also be employed to manipulate the surgical instrument 108.

FIG. 5 is a perspective view of an alternative example robotic manipulator 502, used in conjunction with two robotic manipulators similar to the robotic manipulators 306 described in FIG. 4. As illustrated, a surgical instrument 108 is supported by the robotic manipulator 502 between the two robotic manipulators 306 generally described above. Those of ordinary skill in the art will appreciate that various embodiments of the present invention may incorporate a wide variety of alternative robotic structures, including those described in U.S. Pat. No. 5,878,193, the contents of which are hereby incorporated by reference. Additionally, while the data communication between a robotic component and the processor of the robotic surgical system is primarily described herein with reference to communication between the surgical instrument 108 and the master controller 102a (FIG. 2), it should be understood that similar communication may take place between circuitry of a robotic manipulator, a set-up joint, an endoscope or other image capture device, or the like, and the processor of the robotic surgical system for component compatibility verification, component-type identification, component calibration (such as off-set or the like) communication, confirmation of coupling of the component to the robotic surgical system, or the like.

FIG. 6 is side view of an example surgical tool 600 that may incorporate some or all of the principles of the present disclosure. The surgical tool 600 may be the same as or similar to the surgical instrument(s) 108 of FIGS. 1 and 3-5 and, therefore, may be used in conjunction with a robotic surgical system, such as the robotic surgical system 100 of

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FIG. 1. Accordingly, the surgical tool 600 may be designed to be releasably coupled to a tool driver included in the robotic surgical system 100. In other embodiments, however, the surgical tool 600 may be adapted for use in a manual or hand-operated manner, without departing from the scope of the disclosure.

As illustrated, the surgical tool 600 includes an elongate shaft 602, an end effector 604, a wrist 606 (alternately referred to as a “wrist joint”) that couples the end effector 604 to the distal end of the shaft 602, and a drive housing 608 coupled to the proximal end of the shaft 602. In applications where the surgical tool is used in conjunction with a robotic surgical system (e.g., the robotic surgical system 100 of FIG. 1), the drive housing 608 can include coupling features that releasably couple the surgical tool 600 to the robotic surgical system.

The terms “proximal” and “distal” are defined herein relative to a robotic surgical system having an interface configured to mechanically and electrically couple the surgical tool 600 (e.g., the housing 608) to a robotic manipulator. The term “proximal” refers to the position of an element closer to the robotic manipulator and the term “distal” refers to the position of an element closer to the end effector 604 and thus further away from the robotic manipulator. Alternatively, in manual or hand-operated applications, the terms “proximal” and “distal” are defined herein relative to a user, such as a surgeon or clinician. The term “proximal” refers to the position of an element closer to the user and the term “distal” refers to the position of an element closer to the end effector 604 and thus further away from the user. Moreover, the use of directional terms such as above, below, upper, lower, upward, downward, left, right, and the like are used in relation to the illustrative embodiments as they are depicted in the figures, the upward or upper direction being toward the top of the corresponding figure and the downward or lower direction being toward the bottom of the corresponding figure.

During use of the surgical tool 600, the end effector 604 is configured to move (pivot) relative to the shaft 602 at the wrist 606 to position the end effector 604 at desired orientations and locations relative to a surgical site. The housing 608 includes (contains) various mechanisms designed to control operation of various features associated with the end effector 604 (e.g., clamping, firing, rotation, articulation, energy delivery, etc.). In at least some embodiments, the shaft 602, and hence the end effector 604 coupled thereto, is configured to rotate about a longitudinal axis A_1 of the shaft 602. In such embodiments, at least one of the mechanisms included (housed) in the housing 608 is configured to control rotational movement of the shaft 602 about the longitudinal axis A_1 .

The surgical tool 600 can have any of a variety of configurations capable of performing at least one surgical function. For example, the surgical tool 600 may include, but is not limited to, forceps, a grasper, a needle driver, scissors, an electro cautery tool, a stapler, a clip applier, a hook, a spatula, a suction tool, an irrigation tool, an imaging device (e.g., an endoscope or ultrasonic probe), or any combination thereof. In some embodiments, the surgical tool 600 may be configured to apply energy to tissue, such as radio frequency (RF) energy.

The shaft 602 is an elongate member extending distally from the housing 608 and has at least one lumen extending therethrough along its axial length. In some embodiments, the shaft 602 may be fixed to the housing 608, but could alternatively be rotatably mounted to the housing 608 to allow the shaft 602 to rotate about the longitudinal axis A_1 .

In yet other embodiments, the shaft **602** may be releasably coupled to the housing **608**, which may allow a single housing **608** to be adaptable to various shafts having different end effectors.

The end effector **604** can have a variety of sizes, shapes, and configurations. In the illustrated embodiment, the end effector **604** comprises surgical scissors that include opposing jaws **610**, **612** (alternately referred to as “blades”) configured to move (articulate) between open and closed positions. As will be appreciated, however, the opposing jaws **610**, **612** may alternatively form part of other types of end effectors such as, but not limited to, a tissue grasper, a clip applier, a needle driver, a babcock including a pair of opposed grasping jaws, bipolar jaws (e.g., bipolar Maryland grasper, forceps, a fenestrated grasper, etc.), etc. One or both of the jaws **610**, **612** may be configured to pivot at the wrist **606** to articulate the end effector **604** between the open and closed positions.

FIG. 7 illustrates the potential degrees of freedom in which the wrist **606** may be able to articulate (pivot). The wrist **606** can have any of a variety of configurations. In general, the wrist **606** comprises a joint configured to allow pivoting movement of the end effector **604** relative to the shaft **602**. The degrees of freedom of the wrist **606** are represented by three translational variables (i.e., surge, heave, and sway), and by three rotational variables (i.e., Euler angles or roll, pitch, and yaw). The translational and rotational variables describe the position and orientation of a component of a surgical system (e.g., the end effector **604**) with respect to a given reference Cartesian frame. As depicted in FIG. 7, “surge” refers to forward and backward translational movement, “heave” refers to translational movement up and down, and “sway” refers to translational movement left and right. With regard to the rotational terms, “roll” refers to tilting side to side, “pitch” refers to tilting forward and backward, and “yaw” refers to turning left and right.

The pivoting motion can include pitch movement about a first axis of the wrist **606** (e.g., X-axis), yaw movement about a second axis of the wrist **606** (e.g., Y-axis), and combinations thereof to allow for 360° rotational movement of the end effector **604** about the wrist **606**. In other applications, the pivoting motion can be limited to movement in a single plane, e.g., only pitch movement about the first axis of the wrist **606** or only yaw movement about the second axis of the wrist **606**, such that the end effector **604** moves only in a single plane.

Referring again to FIG. 6, the surgical tool **600** may also include a plurality of drive cables (obscured in FIG. 6) that form part of a cable driven motion system configured to facilitate movement of (articulate) the end effector **604** relative to the shaft **602**. Moving (actuating) the drive cables moves the end effector **604** between an unarticulated position and an articulated position. The end effector **604** is depicted in FIG. 6 in the unarticulated position where a longitudinal axis A_2 of the end effector **604** is substantially aligned with the longitudinal axis A_1 of the shaft **602**, such that the end effector **604** is at a substantially zero angle relative to the shaft **602**. Due to factors such as manufacturing tolerance and precision of measurement devices, the end effector **604** may not be at a precise zero angle relative to the shaft **602** in the unarticulated position, but nevertheless be considered “substantially aligned” thereto. In the articulated position, the longitudinal axes A_1 , A_2 would be angularly offset from each other such that the end effector **604** is at a non-zero angle relative to the shaft **602**.

Still referring to FIG. 6, the surgical tool **600** may be supplied with electrical power (current) via a power cable **614** coupled to the housing **608**. In other embodiments, the power cable **614** may be omitted and electrical power may be supplied to the surgical tool **600** via an internal power source, such as one or more batteries or fuel cells. For purposes of the present description, however, it will be assumed that electrical power is provided to the surgical tool **600** via the power cable **614**. In either case, the surgical tool **600** may alternatively be characterized and otherwise referred to herein as an “electrosurgical instrument” capable of providing electrical energy to the end effector **604**.

The power cable **614** may place the surgical tool **600** in communication with a generator **616** that supplies energy, such as electrical energy (e.g., radio frequency energy), ultrasonic energy, microwave energy, heat energy, or any combination thereof, to the surgical tool **600** and, more particularly, to the end effector **604**. Accordingly, the generator **616** may comprise a radio frequency (RF) source, an ultrasonic source, a direct current source, and/or any other suitable type of electrical energy source that may be activated independently or simultaneously.

In applications where the surgical tool **600** is configured for bipolar operation, the power cable **614** will include a supply conductor and a return conductor. Current can be supplied from the generator **616** to an active (or source) electrode located at the end effector **604** via the supply conductor, and current can flow back to the generator **616** via a return conductor located at the end effector **604** via the return conductor. In the case of a bipolar grasper with opposing jaws, for example, the jaws serve as the electrodes where the proximal end of the jaws are isolated from one another and the inner surface of the jaws (i.e., the area of the jaws that grasp tissue) apply the current in a controlled path through the tissue. In applications where the surgical tool **600** is configured for monopolar operation, the generator **616** transmits current through a supply conductor to an active electrode located at the end effector **604**, and current is returned (dissipated) through a return electrode (e.g., a grounding pad) separately located on a patient’s body.

FIG. 8 is an enlarged isometric view of the distal end of the surgical tool **600** of FIG. 6. More specifically, FIG. 8 depicts enlarged views of the end effector **604** and the wrist **606**, with the end effector **604** in the unarticulated position. The wrist **606** operatively couples the end effector **604** to the shaft **602**. To accomplish this, the wrist **606** includes a distal clevis **802a** and a proximal clevis **802b**. The end effector **604** (i.e., the jaws **610**, **612**) is rotatably mounted to the distal clevis **802a** at a first axle **804a**, the distal clevis **802a** is rotatably mounted to the proximal clevis **802b** at a second axle **804b**, and the proximal clevis **802b** is coupled to a distal end **806** of the shaft **602**.

The wrist **606** provides a first pivot axis P_1 that extends through the first axle **804a** and a second pivot axis P_2 that extends through the second axle **804b**. The first pivot axis P_1 is substantially perpendicular (orthogonal) to the longitudinal axis A_2 of the end effector **604**, and the second pivot axis P_2 is substantially perpendicular (orthogonal) to both the longitudinal axis A_2 and the first pivot axis P_1 . Movement about the first pivot axis P_1 provides “yaw” articulation of the end effector **604**, and movement about the second pivot axis P_2 provides “pitch” articulation of the end effector **604**. In the illustrated embodiment, the jaws **610**, **612** are mounted at the first pivot axis P_1 , thereby allowing the jaws **610**, **612** to pivot relative to each other to open and close the end effector **604** or alternatively pivot in tandem to articulate the orientation of the end effector **604**.

A plurality of drive cables, shown as drive cables **808a**, **808b**, **808c**, and **808d**, extend longitudinally within a lumen **810** defined by the shaft **602** and pass through the wrist **106** to be operatively coupled to the end effector **604**. While four drive cables **808a-d** are depicted in FIG. 8, more or less than 5 four drive cables **808a-d** may be included, without departing from the scope of the disclosure.

The drive cables **808a-d** form part of the cable driven motion system briefly described above, and may be referred to and otherwise characterized as cables, bands, lines, cords, 10 wires, ropes, strings, twisted strings, elongate members, etc. The drive cables **808a-d** can be made from a variety of materials including, but not limited to, metal (e.g., tungsten, stainless steel, etc.) or a polymer. Example drive cables are described in U.S. Patent Pub. No. 2015/0209965 entitled “Compact Robotic Wrist,” and U.S. Patent Pub. No. 2015/0025549 entitled “Hyperdexterous Surgical System,” the contents of which are hereby incorporated by reference. The lumen **810** can be a single lumen, as illustrated, or can alternatively comprise a plurality of independent lumens that 20 each receive one or more of the drive cables **808a-d**.

The drive cables **808a-d** extend proximally from the end effector **604** to the drive housing **608** (FIG. 6) where they are operatively coupled to various actuation mechanisms or devices housed (contained) therein to facilitate longitudinal movement (translation) of the drive cables **808a-d** within the lumen **810**. Selective actuation of all or a portion of the drive cables **808a-d** causes the end effector **604** (e.g., one or both of the jaws **610**, **612**) to articulate (pivot) relative to the shaft **602**. More specifically, selective actuation causes a corresponding drive cable **808a-d** to translate longitudinally within the lumen **810** and thereby cause pivoting movement of the end effector **604**. One or more drive cables **808a-d**, for example, may translate longitudinally to cause the end effector **604** to articulate (e.g., both of the jaws **610**, **612** angled in a same direction), to cause the end effector **604** to open (e.g., one or both of the jaws **610**, **612** move away from the other), or to cause the end effector **604** to close (e.g., one or both of the jaws **610**, **612** move toward the other).

Moving the drive cables **808a-d** can be accomplished in a variety of ways, such as by triggering an associated actuator or mechanism operatively coupled to or housed within the drive housing **608** (FIG. 6). Moving a given drive cable **808a-d** constitutes applying tension (i.e., pull force) to the given drive cable **808a-d** in a proximal direction, which causes the given drive cable **808a-d** to translate and thereby cause the end effector **604** to move (articulate) relative to the shaft **602**.

The wrist **606** includes a first plurality of pulleys **812a** and a second plurality of pulleys **812b**, each configured to interact with and redirect the drive cables **808a-d** for engagement with the end effector **604**. The first plurality of pulleys **812a** is mounted to the proximal clevis **802b** at the second axle **804b** and the second plurality of pulleys **812b** is also mounted to the proximal clevis **802b** but at a third axle **804c** located proximal to the second axle **804b**. The first and second pluralities of pulleys **812a,b** cooperatively redirect the drive cables **808a-d** through an “S” shaped pathway before the drive cables **808a-d** are operatively coupled to the end effector **604**.

In at least one embodiment, one pair of drive cables **808a-d** is operatively coupled to each jaw **610**, **612** and configured to “antagonistically” operate the corresponding jaw **610**, **612**. In the illustrated embodiment, for example, a first connector **814** couples the first and second drive cables **808a,b**, and a second connector (occluded) similarly couples the third and fourth drive cables **808c,d**.

Actuation of the first drive cable **808a** acts on the first connector **814** and thereby pivots the second jaw **612** about the first pivot axis P_1 toward the open position. In contrast, actuation of the second drive cable **808b** also acts on the first connector **814** but pivots the second jaw **612** about the first pivot axis P_1 in the opposite direction and toward the closed position. Similarly, actuation of the third drive cable **808c** acts on the second connector (occluded) and thereby pivots the first jaw **610** about the first pivot axis P_1 toward the open position, while actuation of the fourth drive cable **808d** also acts on the second connector (occluded) but pivots the first jaw **610** about the first pivot axis P_1 in the opposite direction and toward the closed position.

Accordingly, the drive cables **808a-d** may be characterized or otherwise referred to as “antagonistic” cables that cooperatively (yet antagonistically) operate to cause relative or tandem movement of the first and second jaws **610**, **612**. When the first drive cable **808a** is actuated (moved), the second drive cable **808b** naturally follows as coupled to the first drive cable **808a** at the first connector **814**, and vice versa. Similarly, when the third drive cable **808c** is actuated, the fourth drive cable **808d** naturally follows as coupled to the third drive cable **808c** at the second connector (occluded), and vice versa.

The first connector **814** and the occluded second connector may comprise any attachment mechanism capable of coupling the first and second drive cables **808a,b** and the third and fourth drive cables **808c,d**, respectively, such that movement (actuation) of one drive cable correspondingly moves the other, and vice versa. In the illustrated embodiment, for example, the first connector **814** (and the occluded second connector) may comprise a ball crimp. In other embodiments, however, the first connector **814** (and the occluded second connector) may include, but is not limited to, a welded attachment, a brazed attachment, an adhesive bond, a mechanical fastener, or any combination thereof.

The surgical tool **600** may also include an electrical conductor **816** that supplies electrical energy to the end effector **604**, thereby converting the surgical tool **600** into an “electrosurgical instrument”. Similar to the drive cables **808a-d**, the electrical conductor **816** extends longitudinally within the lumen **810** and passes through the wrist **106** to be operatively (and electrically) coupled to the end effector **604**. In some embodiments, the electrical conductor **816** and the power cable **614** (FIG. 6) may comprise the same structure. In other embodiments, however, the electrical conductor **816** may be electrically coupled to the power cable **614**. In yet other embodiments, the electrical conductor **816** may extend to the drive housing **608** (FIG. 6) where it is electrically coupled to an internal power source, such as batteries or fuel cells.

The electrical conductor **816** may comprise a supply conductor **818** encapsulated by an insulating cover (e.g., an insulated wire). In the illustrated embodiment, the end effector **604** is configured for monopolar operation. Accordingly, electrical energy is transmitted by the supply conductor **818** to the end effector **604**, which acts as an active (or source) electrode. In at least one embodiment, the electrical energy may comprise radio frequency (“RF”) energy exhibiting a frequency between about 100 kHz and 1 MHz. Low frequency RF energy causes ionic agitation or friction, in effect resistive heating, thereby increasing the temperature of target tissue. Accordingly, electrical energy supplied to the end effector **604** is converted to heat and transferred to adjacent tissue to cut, cauterize, and/or coagulate the tissue (dependent upon the localized heating of the tissue), and thus may be particularly useful for sealing blood vessels or

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diffusing bleeding. Electrical energy is then returned from the tissue through a return electrode, which typically comprises a grounding pad separately located on a patient's body.

Monopolar electrosurgical instruments, however, have at least one downside that is especially evident when used in laparoscopic procedures. Unless properly insulated, the active electrode of the end effector **604** may inadvertently arc between conductive materials, such as electrically conductive component parts of the end effector **604** (e.g., the distal clevis **802a**). In such cases, stray electrical current may be transmitted to unseen and/or untargeted tissue, which could potentially injure the patient by causing unintended or unknown damage or ablations to the patient's tissue. According to embodiments of the present disclosure, the end effector **604** may be designed and otherwise configured to insulate the electrical conductor **816** from conductive materials that form part of the end effector **604**.

FIG. **9** is an enlarged view of the end effector **604** of FIG. **8**. As mentioned above, the end effector **604** includes the first and second jaws **610**, **612** rotatably mounted to the distal clevis **802a** at the first axle **804a**. A portion of the electrical conductor **816** is also depicted extending to the end effector **604** to provide electrical energy to the first jaw **610** via the insulated supply conductor **818**. The drive cables **808a-d** of FIG. **8** are omitted to enable better viewing of the component parts of the end effector **604**.

As illustrated in FIG. **9**, the end effector **604** further includes a first jaw holder **902a** and a second jaw holder **902b** laterally offset from the first jaw holder **902a**. The first jaw holder **902a** is mounted to the first axle **804a** and configured to receive and seat the first jaw **610** such that movement (rotation) of the first jaw holder **902a** about the first pivot axis P_1 correspondingly moves (rotates) the first jaw **610**. The first jaw holder **902a** may also provide and otherwise define a first pulley **904a** configured to receive and seat one or more drive cables, such as the third and fourth drive cables **808c,d** of FIG. **8**, to effect such movement (rotation). The second jaw holder **902b** is similarly mounted to the first axle **804a** and is configured to receive and seat the second jaw **612** such that movement (rotation) of the second jaw holder **902b** about the first pivot axis P_1 correspondingly moves (rotates) the second jaw **612**. The second jaw holder **902b** may also provide and otherwise define a second pulley **904b** configured to receive and seat one or more drive cables, such as the first and second drive cables **808a,b** of FIG. **8**, to effect such movement (rotation).

The term "jaw holder," as used herein, is intended to apply to a variety of types of end effectors having opposing jaws or blades that are movable relative to one another. In the illustrated embodiment, the jaws **610**, **612** comprise opposing scissor blades of a surgical scissors end effector. Accordingly, the jaw holders **902a,b** may alternately be referred to as "blade holders". In other embodiments, however, the jaws **610**, **612** may alternatively comprise opposing jaws used in a grasper end effector, or the like, and the term "jaw holder" similarly applies, without departing from the scope of the disclosure. Moreover, the term "holder" in "jaw holder" may be replaced with "mount," "drive member," or "actuation member."

The first and second jaw holders **902a,b** may be made of any electrically insulating or non-conductive material. Suitable non-conductive materials include, but are not limited to, a ceramic (e.g., zirconia, alumina, aluminum nitride, a silicate, silicon nitride, etc.), high temperature and high strength plastics, a thermoplastic or thermosetting polymer (e.g., polyether ether ketone, ULTEM™, VESPEL®, a poly-

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phenylsulfone, a polysulfone, RADEL®, a polyamide-imide, a polyimide, an epoxy, etc.), a composite material (e.g., fiberglass), hard rubber (e.g., ebonite), or any combination thereof. Alternatively, the proximal region of the jaws **610**, **612** may be coated in a nonconductive material (e.g., ceramic) to isolate the proximal regions of the jaws **610**, **612** from the jaw holders **902a,b** that isolated the jaws **610**, **612** from the rest of the wrist components, thus allowing these wrist components to be constructed out of a traditional conductive material such as stainless steel.

In some embodiments, the first jaw holder **902a** may comprise a monolithic structure made of a single non-conductive material. In other embodiments, however, the first jaw holder **902a** may comprise a first portion **906a** and a second portion **906b** coupled to the first portion **906a**. In the illustrated embodiment, the first portion **906a** may be configured to receive the first jaw **610** and the second portion **906b** may provide the first pulley **904a**. In some embodiments, the first and second portions **906a,b** may be made of dissimilar materials. In such embodiments, for example, the first portion **906a** may be made of a non-conductive material (e.g., ceramic or a polymer) and the second portion **906b** may be made of a dissimilar non-conductive material or alternatively a conductive material. In other embodiments, however, the first and second portions **906a,b** may be made of dissimilar non-conductive materials. In such embodiments, for example, the first portion **906a** may be made of ceramic, and the second portion **906b** may be made of a plastic, which may be overmolded onto the first portion **906a** and otherwise coupled thereto. As will be appreciated, the foregoing alternative embodiments may be equally applicable to the second jaw holder **902b**, without departing from the scope of the disclosure.

The end effector **604** may further include at least one spacer that interposes the first and second jaw holders **902a,b**. In the illustrated embodiment, the end effector **604** includes a first spacer **908a** configured to be received by the first jaw holder **902a** and a second spacer **908b** configured to be received by the second jaw holder **902b**. During operation, the first and second spacers **908a,b** may slidably engage (rub against) each other as the opposing jaws **610**, **612** rotate about the first pivot axis P_1 between open and closed positions.

To reduce friction and drag force generated between the two structures, the first and second spacers **908a,b** may be made of a lubricious (e.g., slippery or slick) material. Suitable lubricious materials include, but are not limited to, nylon, polished metal, a smooth plastic, or any combination thereof. In other embodiments, however, the first and second spacers **908a,b** may be coated with a lubricious substance or material such as, but not limited to, oil, graphite, TEF-LON™, silicone, or any combination thereof.

The end effector **604** may further include a first end cap **910a** and a second end cap **910b** (mostly occluded in FIG. **9**). As discussed in more detail below, the first and second end caps **910a,b** may be configured to mount the first axle **804a** to the distal clevis **802a**.

FIG. **10A** is an isometric view of the end effector **604** without the first jaw holder **902a**, and FIG. **10B** is an isometric view of the end effector **604** without the second jaw holder **902b**. In FIG. **10A**, the electrical conductor **816** is shown extending to the end effector **604** to provide electrical energy to the first jaw **610** via the insulated supply conductor **818**. The supply conductor **818** may be received within a pocket **1002** defined in the first jaw **610**. In some embodiments, the supply conductor **818** may be resistance welded or soldered to the pocket **1002**. Electrical energy

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conveyed through the supply conductor **818** will be transferred to the first jaw **610** at the pocket **1002**. Accordingly, the first jaw **610** may effectively be characterized as an active electrode for the end effector **604**, and electrical energy transmitted to the first jaw **610** is transmitted to the second jaw **612** by virtue of contact between the jaws **610**, **612**.

FIGS. **10A** and **10B** also depict how the first axle **804a** may be mounted to the distal clevis **802a**. As illustrated, the distal clevis **802a** includes a first distally-extending arm **1004a** (FIG. **10A**) and a second distally-extending arm **1004b** (FIG. **10B**). The first arm **1004a** defines a first slot **1006a** (FIG. **10A**) configured to receive and secure the first end cap **910a**, and the second arm **1004b** defines a second slot **1006b** (FIG. **10B**) configured to receive and secure the second end cap **910b**. A first end **1008a** (FIG. **10A**) of the first axle **804a** may be received by the first end cap **910a** and a second end **1008b** (FIG. **10B**) of the first axle **804a** may be received by the second end cap **910b**. Once the first and second ends **1008a,b** are received by the first and second end caps **910a,b**, respectively, the end caps **910a,b** may be received and secured within the first and second slots **1006a,b**, respectively.

FIG. **11A** is a partially-exploded view of the first jaw holder **902a** and corresponding first spacer **908a**, and FIG. **11B** is a partially-exploded view of the second jaw holder **902b** and corresponding second spacer **908b**. As illustrated, the first and second spacers **908a,b** may be plate-like structures. In one or more embodiments, the spacers **908a,b** may be made of any of the non-conductive materials mentioned herein.

In FIG. **11A**, the first jaw holder **902a** defines a central aperture **1102a** configured to receive the first axle **804a** (FIGS. **9** and **10A-10B**) to rotatably mount the first jaw holder **902a** thereto. The first jaw holder **902a** also defines a first recess **1104a** configured to receive and seat the first jaw **610** such that movement (rotation) of the first jaw holder **902a** will correspondingly move (rotate) the first jaw **610**. A second recess **1104b** may also be defined by the first jaw holder **902a** to receive and seat the first spacer **908a**.

In FIG. **11B**, the second jaw holder **902b** defines a central aperture **1102b** configured to receive the first axle **804a** (FIGS. **9** and **10A-10B**) to rotatably mount the second jaw holder **902b** thereto. The second jaw holder **902b** also defines a first recess **1106a** configured to receive and seat the second jaw **612** such that movement (rotation) of the second jaw holder **902b** will correspondingly move (rotate) the second jaw **612**. A second recess **1104b** may also be defined by the second jaw holder **902b** to receive and seat the second spacer **908b**.

FIG. **12** is an exploded view of the end effector **604** of FIG. **8**. To assemble the end effector **604**, the first axle **804a** is first extended through the central apertures **1102a,b** of the first and second jaw holders **902a,b**, respectively. The opposing ends **1008a,b** (only first end **1008a** visible in FIG. **12**) of the first axle **804a** may then be received by the first and second end caps **910a,b**, respectively. In some embodiments, the ends **1008a,b** may be press fit into the corresponding end caps **910a,b**, such that an interference fit results. In other embodiments, however, the ends **1008a,b** may be received by the corresponding end caps **910a,b** such that the first axle **804a** is rotatably mounted to the end caps **910a,b**.

The end caps **910a,b** may then be received and secured within the slots **1006a,b** provided on the distal clevis **802a**. In some embodiments, the end caps **910a,b** may be welded or brazed to the corresponding slots **1006a,b**. In such

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embodiments, the end caps **910a,b** may be made of a metal, such as stainless steel or another durable metal that may be welded or brazed to the distal clevis **802a** at the slots **1006a,b**. The first axle **804a** is captured between the two end caps **910a,b** and then held into the clevis **802a** when the caps **910a,b** are welded to the corresponding slots **1006a,b**. During this welding process, the end caps **910a,b** are held in contact with the end surfaces of the first axle **804a**, thus eliminating any part tolerances and subsequent gaps. In other embodiments, the end caps **910a,b** may be secured within the corresponding slots **1006a,b** by other means, such as by using one or more mechanical fasteners, an interference or snap fit, or by orbital riveting of the outer surface of the end caps **910a,b**.

Because several component parts of the end effector **604** are made of non-conductive materials, the monopolar electrical energy supplied to the jaws **610**, **612** may be effectively isolated from electrically-conductive parts of the end effector **604**. For example, the first axle **804a**, one or both of the jaw holders **902a,b**, and one or both of the spacers **908a,b** may each be made of any of the non-conductive materials mentioned herein, which electrically isolates the distal clevis **802a** from the monopolar electrical energy. Consequently, the electrical energy supplied to the jaws **610**, **612** cannot inadvertently arc to the distal clevis **802a** through these parts, which helps reduce the occurrence of unintended or unknown damage or ablations to patient tissue. This also eliminates the need for a separate insulative sleeve to be applied over the entire end effector before use.

FIG. **13** is an enlarged view of another example end effector **1302** that may be used with the surgical tool **600** of FIG. **6**, according to one or more embodiments. Accordingly, in some applications, the end effector **1302** of FIG. **13** may replace the end effector **604** of FIGS. **6** and **8-12**. The end effector **1302** may be similar in some respects to the end effector **604** and therefore may be best understood with reference thereto, where like numerals will represent like component not described again.

Similar to the end effector **604** of FIGS. **6** and **8-12**, the end effector **1302** includes the first and second jaws **610**, **612** rotatably mounted to the distal clevis **802a** at the first axle **804a**. The end effector **1302** also includes the first and second jaw holders **902a,b** that receive and seat the first and second jaws **610**, **612**, respectively, for corresponding movement (rotation) therewith. Furthermore, the end effector **1302** also includes a first end cap **1304a** and a second end cap **1304b** (occluded in FIG. **13**; see FIGS. **14** and **15**). The first and second end caps **1304a,b** may be configured to mount the first axle **804a** to the distal clevis **802a**.

A portion of the electrical conductor **816** is also depicted extending to the end effector **1302** to provide electrical energy to the end effector **1302** via the insulated supply conductor **818**. Unlike the end effector **604** of FIGS. **8-12**, however, the electrical conductor **816** extends to the first axle **804a** and transfers electrical energy directly to the jaws **610**, **612** via a contact plate (not shown) mounted to the first axle **804a**.

FIG. **14** is a cross-sectional front view of the end effector **1302** of FIG. **13**. As illustrated, the electrical conductor **816** extends into a channel **1402** defined in the first axle **804a** and an end of the supply conductor **818** extends distally to engage (or come into close contact with) a contact plate **1404** mounted to the first axle **804a**. The top surface of the contact plate **1404** is positioned and otherwise arranged to transfer electrical energy from the supply conductor **818** to the jaws **610**, **612**.

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In at least one embodiment, the first jaw **610** may define a first arcuate bottom surface **1405a** and the second jaw **612** may define a second arcuate bottom surface **1405b**. The arcuate bottom surfaces **1405a,b** may be configured to slidingly engage the top surface of the contact plate **1404** as the jaws **610**, **612** move between open and closed positions. In other embodiments, however, sliding contact between the opposing structures need not occur since the voltages run through the supply conductor **818** may be sufficient to arc across a small gap between the bottom surfaces **1405a,b** and the top surface of the contact plate **1404**.

FIG. **14** also depicts how the first axle **804a** may be mounted to the distal clevis **802a**. The first arm **1004a** defines a first slot **1406a** configured to receive and secure the first end cap **1304a**, and the second arm **1004b** defines a second slot **1406b** configured to receive and secure the second end cap **1304b**. A first end **1408a** of the first axle **804a** may be received by the first end cap **1304a** and a second end **1408b** of the first axle **804a** may be received by the second end cap **1304b**. In at least one embodiment, the first end cap **1304a** may provide and otherwise define a first pocket **1410a** sized to receive the first end **1408a** of the first axle **804a**, and the second end cap **1304b** may provide and otherwise define a second pocket **1410b** sized to receive the second end **1408b** of the first axle **804a**.

FIG. **15** is an exploded view of the end effector **1302** of FIG. **13**. As illustrated, the contact plate **1404** may comprise an arcuate body **1502** that defines a central aperture **1504**. On either lateral side of the aperture **1504**, the body **1502** provides contact surfaces **1506a** and **1506b**. During operation, the arcuate bottom surfaces **1405a,b** (only the second bottom surface **1405b** is visible in FIG. **15**) of the jaws **610**, **612** may be configured to slidingly engage the contact surfaces **1506a,b**. In other embodiments, however, sliding contact between the opposing structures need not occur since the voltages run through the supply conductor **818** may be sufficient to arc across a small gap between the bottom surfaces **1405a,b** and the top surface of the contact plate **1404**. Moreover, a small gap between the opposing structures may help reduce friction in the assembly.

As best seen in the enlarged, inset graphic of the contact plate **1404**, a contact tab **1508** may extend from the body **1502** within the aperture **1504**. The contact tab **1508** may provide a location where the supply conductor **818** can engage the contact plate **1404** and thereby transmit electrical energy thereto. In some embodiments, the supply conductor **818** may be resistance welded or soldered to the contact tab **1508**. In other embodiments, however, the supply conductor **818** may be in biased engagement with the contact tab **1508** to transmit the electrical energy thereto. In yet other embodiments, the contact tab **1508** may be omitted and the supply conductor **818** may instead be welded or soldered to or in biased engagement with any other portion of the contact plate **1404**, without departing from the scope of the disclosure.

To assemble the end effector **1302**, the contact plate **1404** may first be mounted to the first axle **804a**. In at least one embodiment, the first axle **804a** may define or provide a recess **1510** configured to receive the contact plate **1404** such that a flush mounting arrangement results. The electrical conductor **816** may then be inserted into the channel **1402** defined in the first axle **804a** and the supply conductor **818** may be placed in engagement (contact) with the contact plate **1404** (e.g., the contact tab **1508**) to facilitate transfer of electrical energy.

The first and second jaw holders **902a,b** may then be mounted to the first axle **804a** at the central apertures

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1102a,b, respectively. The first and second jaw holders **902a,b** may be brought into close lateral engagement such that the arcuate bottom surfaces **1405a,b** (only the second bottom surface **1405b** is visible in FIG. **15**) come into contact with (or close proximity without engagement) the contact surfaces **1506a,b**, respectively, of the contact plate **1404**.

The opposing ends **1408a,b** of the first axle **804a** may then be received by the first and second end caps **1304a,b**, respectively. In some embodiments, the ends **1408a,b** may be press fit into the corresponding pockets **1410a,b** (only the second pocket **1410b** is visible in FIG. **15**) of the end caps **1304a,b** such that an interference fit results. In other embodiments, or in addition thereto, the pockets **1410a,b** may provide an inner profile configured to mate with a corresponding outer profile provided by each opposing end **1408a,b**. In the illustrated embodiment, for example, the pockets **1410a,b** may define and otherwise provide a flat inner surface **1512** configured to mate with a corresponding flat outer surface **1514** defined by each end **1408a,b**. The mated relationship between the ends **1408a,b** and the end caps **1304a,b** may prove advantageous in preventing the first axle **804a** from rotating during operation.

The end caps **1304a,b** may then be received and secured within the slots **1406a,b** provided on the distal clevis **802a**. In some embodiments, the end caps **1304a,b** may be welded or brazed to the corresponding slots **1406a,b**. In such embodiments, the end caps **1304a,b** may be made of a metal, such as stainless steel or another durable metal that may be welded or brazed to the distal clevis **802a**. The width of the first axle **804a** may be less than the width of the opening in the distal clevis **802a**, such that during the welding process the end caps **1304a,b** press the jaw holders **902a,b** against one another. In other embodiments, the end caps **1304a,b** may be secured within the corresponding slots **1406a,b** by other means, such as by using one or more mechanical fasteners or through an interference fit, or by orbital riveting of the outer surface of the end caps **910a,b**, without departing from the scope of the disclosure.

According to the present disclosure, one or more component parts of the end effector **1302** are made of non-conductive materials that effectively isolate the distal clevis **802a** from the monopolar energy conducted through the electrical conductor **816** to the jaws **610**, **612**. For example, one or more of the first axle **804a**, the first jaw holder **902a**, and the second jaw holder **902b** may be made of any of the non-conductive materials mentioned herein. Consequently, the electrical energy supplied to the jaws **610**, **612** via the contact plate **1404** cannot inadvertently arc to the distal clevis **802a** through these parts, which helps reduce the occurrence of unintended or unknown damage or ablations to the patient's tissue.

FIG. **16** is an isometric view of a portion of another example end effector **1602**, according to one or more embodiments. More specifically, FIG. **16** depicts a jaw **1604** and a corresponding jaw holder **1606** of the end effector **1602**. While not shown, the end effector **1602** may further include a second jaw and a corresponding second jaw holder configured to operate in tandem with the illustrated jaw **1604** as a tissue grasper, for example. As will be appreciated, the following description of the jaw **1604** and the jaw holder **1606** may be equally applicable to the opposing, non-illustrated second jaw and corresponding second jaw holder. Accordingly, the end effector **1602** may be similar in some respects to the end effector **604** of FIGS. **8-12** and, in some

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applications, the end effector **1602** may replace the end effector **604** and may be used with the surgical tool **600** of FIG. 6.

The jaw holder **1606** secures the jaw **1604** such that movement (rotation) of the jaw holder **1606** during operation correspondingly moves (rotates) the jaw **1604**. As illustrated, the jaw holder **1606** provides and otherwise defines a pulley **1608** configured to receive and seat one or more drive cables, such as the first and second drive cables **808a,b** of FIG. 8. A pocket **1610** may be defined on the pulley **1608** to receive and seat the connector **814**, which couples the drive cables **808a,b** to effect movement (rotation) of the jaw holder **1606**, as generally described above. The jaw holder **1606** also defines a central aperture **1612** configured to receive an axle (e.g., the first axle **804a** of FIGS. 9 and 10A-10B) to rotatably mount the jaw holder **1606** thereto.

A portion of an electrical conductor **1614** is also depicted extending to the end effector **1602** to provide electrical energy to the end effector **1602** (i.e., the jaw **1604**). The electrical conductor **1614** may be similar to (or the same as) the electrical conductor **816** of FIG. 9 and, therefore, may include a supply conductor **1616** encased in an insulative covering. The supply conductor **1616** may be electrically coupled to the jaw **1604**, thereby making the jaw an active (or source) electrode for the end effector **1602**. In some embodiments, the end effector **1602** is configured for monopolar operation using only the electrical conductor **1614**. In other embodiments, however, end effector **1602** may be configured for bipolar operation. In such embodiments, the end effector **1602** may include a second electrical conductor extending to and electrically coupling to a second jaw (not shown) of the end effector **1602**, and thereby making the second jaw a return electrode.

The jaw holder **1606** may be made of any of the electrically insulating or non-conductive materials mentioned herein. In some embodiments, the jaw holder **1606** may comprise a monolithic structure made of a single non-conductive material. In other embodiments, however, the jaw holder **1606** may comprise a first portion **1618a** and a second portion **1618b** coupled to the first portion **1618a**. The first portion **1618a** may be configured to receive and secure the jaw **1604** and provide the pulley **1608**, and the second portion **1618b** may be configured to fully encapsulate and insulate the supply conductor **1616** at the jaw **1604**. The first portion **1618a** may be molded (e.g., overmolded) onto the jaw **1604** via a first injection molding shot, and the second portion **1618b** may be overmolded onto the first portion **1618a** via a second injection molding shot. In some embodiments, the first and second portions **1618a,b** may be made of the same non-conductive material, but could alternatively be made of dissimilar non-conductive materials, without departing from the scope of the disclosure.

Since the portions **1618a,b** of the jaw holder **1606** are made of non-conductive materials and are formed to fully insulate the supply conductor **1616** at the jaw **1604**, the electrical energy supplied to the jaw **1604** may be effectively isolated from adjacent electrically-conductive parts of the end effector **1602**, such as an axle (e.g., the first axle **804a** of FIG. 8), the drive cables **808a,b**, or a clevis (e.g., the distal clevis **802a** of FIG. 8). Consequently, the electrical energy supplied to the jaw **1604** may have a reduced risk of inadvertent tissue damage due to unintended current leakage to electrically-conductive parts of the end effector **1602**. Additionally, this method fully encapsulates the assembly, and reduces the number of parts, interfaces, and possible

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crevices where biomaterials may gather. Consequently, this should make the part much easier to clean and sterilize.

FIGS. 17, 18A-18B, 19, and 20A-20B illustrate progressive views of an example process of manufacturing the portion of the end effector **1602** of FIG. 16, according to one or more embodiments. FIG. 17 is an isometric side view of the jaw **1604** of FIG. 16. The jaw **1604** may be made of a variety of electrically-conductive materials, such as metal. In at least one embodiment, the jaw **1604** may be made of s are 17-4 stainless steel, but could alternatively be made of any conductive, high strength material that is resistant to chemical attack, such as a high strength stainless steel. In some applications, the jaw **1604** may be coated to impart specific properties. For example, the jaw **1604** may be coated to provide a release layer or to prevent corrosion. The jaw **1604** may be machined from a larger piece of material or may alternatively be manufactured, such as through metal injection molding (MIM), machining, stamping, 3D printing, or any combination thereof.

As illustrated, the jaw **1604** includes a tissue engagement portion **1702**, a shank **1704** that extends from the tissue engagement portion **1702**, and a contact plate **1706** coupled to or forming part of the shank **1704**. The contact plate **1706** may provide a location where the supply conductor **1616** (FIG. 16) is coupled to the jaw **1604** to convey electrical energy thereto. The contact plate **1706** may define a pinhole **1708** through which the supply conductor **1616** may extend to access the contact plate **1706**.

In some embodiments, the jaw **1604** may also define a through hole **1710** and a central aperture **1712**. The through hole **1710** may prove advantageous in helping couple the supply conductor **1616** to the contact plate **1706** and in helping lock the jaw **1604** to the jaw holder **1606** (FIG. 16), as discussed more below. The central aperture **1712** may be configured to co-axially align with the central aperture **1612** (FIG. 16) of the jaw holder **1606** to receive an axle (e.g., the first axle **804a** of FIGS. 9 and 10A-10B) therethrough.

FIGS. 18A and 18B are front and back views, respectively, of the first portion **1618a** of the jaw holder **1606** following a first injection molding process, according to one or more embodiments. The first portion **1618a** may be formed over a portion of the shank **1704** and the contact plate **1706**. The first injection molding process may alternatively be referred to as a first “overmold shot.”

In FIG. 18A, the first portion **1618a** provides and otherwise defines a cable passage **1802** that communicates with the contact plate **1706** via the pinhole **1708**. The electrical conductor **1614** (FIG. 16) may be routed through the cable passage **1802** to allow the supply conductor **1616** (FIG. 16) to electrically communicate with (i.e., transmit electrical energy to) the contact plate **1706**. In some embodiments, one or more retention features **1804** may be provided in the cable passage **1802** to help capture the electrical conductor **1614**, as discussed in more detail below.

In FIG. 18B, the first portion **1618a** may further provide an access passage **1806** eccentric to the central aperture **1612**. The access passage **1806** communicates with the through hole **1710** (FIG. 18A) defined in the jaw **1604**. During the first overmold shot, the access passage **1806** can be used to locate and align the jaw to the plastic tooling, and thus operates as a “tooling shut off.” Moreover, the access passage **1806** and the through hole **1710** cooperatively facilitate access to the contact plate **1706**, which may help couple the supply conductor **1616** to the contact plate **1706**, as described herein. Accordingly, the access passage **1806** may operate as an “electrode access point.” Once the part is overmolded in a second overmolding step (discussed

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below), the access passage **1806** may help provide a robust mechanical interlock, and this operates as an “interlock channel.”

FIG. **19** depicts the electrical conductor **1614** received within the first portion **1618a** of the jaw holder **1606**. Following the first overmold shot that produces the first portion **1618a**, the electrical conductor **1614** may be coupled to and placed in electrical communication with the jaw **1604**. More specifically, the electrical conductor **1614** may be routed through and received by the cable passage **1802**. A portion of the insulation layer may be stripped from the electrical conductor **1614** to expose the supply conductor **1616**, and the exposed portion of the supply conductor **1616** may be extended through the pinhole **1708** to access the contact plate **1706**.

The supply conductor **1616** may then be coupled to the contact plate **1706**, such as through resistance welding or soldering. In some embodiments, resistance welding may be preferred over soldering as it provides a stronger bond without potentially hardening the electrical conductor **1614** as a result of solder wicking. The coaxially aligned through hole **1710** and access passage **1806** allows a resistance welder access for electrodes to form an opposing contact weld.

The retention features **1804** may be configured to engage the outer insulative layer of the electrical conductor **1614** and thereby help retain the electrical conductor **1614** within the cable passage **1802**. As illustrated, the retention features **1804** may comprise angled teeth or protrusions that extend radially into the cable passage **1802**, but could alternatively comprise any other type of structure capable of gripping the outer surface of the electrical conductor **1614**. In operation, the retention features **1804** substantially prevent the electrical conductor **1614** from reversing back through the cable passage **1802**. This may prove advantageous in providing strain relief on the electrical conductor **1614** by helping to mitigate strain over several cycles of using the end effector **1602** (FIG. **16**). Moreover, the retention features **1804** may prove advantageous in helping prevent the electrical conductor **1614** from moving during a second overmold shot used to form the second portion **1618b** (FIGS. **20A** and **20B**).

FIGS. **20A** and **20B** are front and back views, respectively, of the end effector **1602** following a second injection molding process that forms the second portion **1618b** of the jaw holder **1606**, according to one or more embodiments. The second portion **1618b** may be formed over the first portion **1618a** and the injection pressure may be sized to prevent excess flash. The second injection molding process may alternately be referred to as a second “overmold shot.”

As seen in FIG. **20A**, during the second overmold shot, the material for the second portion **1618b** (e.g., plastic) fills and encapsulates a cavity **2002** that contains the contact plate **1706** (FIG. **19**) and the exposed portion of the supply conductor **1616** (FIG. **19**). Accordingly, the second overmold shot electrically isolates and insulates the contact plate **1706** and the adjacent supply conductor **1616**. Moreover, as seen in FIG. **20B**, the second overmold shot may also fill in the access passage **1806**. As will be appreciated, filling in the cavity **2002** and the access passage **1806** helps lock the first and second portions **1618a,b** together and helps prevent separation.

Accordingly, the second overmold shot encapsulates and electrically isolates the supply conductor **1616** and the jaw **1604** from adjacent electrically-conductive parts of the end effector **1602** (FIG. **16**), which decreases the risk of inadvertent arcing due to creepage and clearance failure. The two

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overmolding shots also help fill in cracks and crevices in the end effector **1602** that might present a bioburden risk.

FIG. **21** is an isometric view of another example end effector **2102** that may be used with the surgical tool **600** of FIG. **6**, according to one or more embodiments. Accordingly, in some applications, the end effector **2102** may replace the end effector **604** of FIG. **6**. The end effector **2102** may be similar in some respects to the end effector **1602** of FIG. **16** and, therefore, may be best understood with reference thereto. The end effector **2102** includes a jaw **2104** and a corresponding jaw holder **2106**. In the illustrated embodiment, the jaw **2104** is in the form of a surgical hook, but might alternatively comprise a surgical spatula or any other type of end effector tool.

The jaw holder **2106** secures the jaw **2104** such that movement (rotation) of the jaw holder **2106** during operation correspondingly moves (rotates) the jaw **2104**. As illustrated, the jaw holder **2106** provides and otherwise defines a first pulley **2108a** and a second pulley **2108b** (partially occluded). Each pulley **2108a,b** is configured to receive and seat one or more drive cables. In the illustrated embodiment, for instance, the first pulley **2108a** receives the first and second drive cables **808a,b** of FIG. **8**, and the second pulley **2108b** receives the third and fourth drive cables **808c,d** of FIG. **8**. A pocket **2110** may be defined on the pulley **2108a** to receive and seat the connector **814**, which couples the first and second drive cables **808a,b** to effect movement (rotation) of the jaw holder **2106**, as generally described above. A second pocket (not shown) is defined on the opposing side of the end effector **2102** to receive and seat a second connector (not shown) that couples the third and fourth drive cables **808a,b** to effect movement (rotation) of the jaw holder **2106**.

The jaw holder **2106** also defines a central aperture **2112** configured to receive an axle (e.g., the first axle **804a** of FIGS. **9** and **10A-10B**) to rotatably mount the jaw holder **2106** thereto.

A portion of an electrical conductor **2114** is also depicted extending to the end effector **2102** to provide electrical energy to the end effector **2102** (i.e., the jaw **2104**). The electrical conductor **2114** may be similar to (or the same as) the electrical conductor **816** of FIG. **9** and, therefore, may include a supply conductor **2116** encased in an insulative covering. The supply conductor **2116** may be electrically coupled to the jaw **2104**, thereby making the jaw **2104** an active (or source) electrode for the end effector **2102**. In the illustrated embodiment, the end effector **2102** is configured for monopolar operation.

Similar to the jaw holder **1606** of FIG. **16**, the jaw holder **2106** may be made of any of the electrically insulating or non-conductive materials mentioned herein. In some embodiments, the jaw holder **2106** may comprise a monolithic structure made of a single non-conductive material. In other embodiments, however, the jaw holder **2106** may comprise a first portion **2118a** and a second portion **2118b** coupled to the first portion **2118a**. The first portion **2118a** may be configured to receive and secure the jaw **2104** and provide the first pulley **2108a**, and the second portion **2118b** may be configured to fully encapsulate and insulate the supply conductor **2116** at the jaw **2104** and provide the second pulley **2108b**. As described below, the first portion **2118a** may be molded (e.g., overmolded) onto the jaw **2104** via a first injection molding process, and the second portion **2118b** may be overmolded onto the first portion **2118b** via a second injection molding process. In some embodiments, the first and second portions **2118a,b** may be made of the same non-conductive material, but could alternatively be

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made of dissimilar non-conductive materials, without departing from the scope of the disclosure.

Since the portions **2118a,b** of the jaw holder **2106** are made of non-conductive materials and are formed to fully insulate the supply conductor **2116** at the jaw **2104**, the electrical energy supplied to the jaw **2104** may be effectively isolated from adjacent electrically-conductive parts of the end effector **2102**, such as an axle (e.g., the first axle **804a** of FIG. 8), the drive cables **808a-d**, or a clevis (e.g., the distal clevis **802a** of FIG. 8). Consequently, the electrical energy supplied to the jaw **2104** may reduce the risk of inadvertent tissue damage due to unintended current leakage to electrically-conductive parts of the end effector **2102**. Additionally, this method fully encapsulates the assembly, and reduces the number of parts, interfaces, and possible crevices where biomaterials may gather. Consequently, this should make the part much easier to clean and sterilize.

FIGS. 22, 23, 24A-24B, 25, and 26A-26B illustrate progressive views of an example process of manufacturing the end effector **2102** of FIG. 21, according to one or more embodiments. FIG. 22 is an isometric side view of the jaw **2104** of FIG. 21. As illustrated, the jaw **2104** includes a hook member **2202** and an isolator **2204**. The hook member **2202** may include a shank **2206** sized to be received within a central passageway **2208** defined through the isolator **2204**. In at least one embodiment, the end of the shank **2206** may define a planar surface **2210**. In some embodiments, the isolator **2204** may provide and otherwise define a mold profile **2212** that may help secure the jaw **2104** to the jaw holder **2106** (FIG. 21) during an injection molding process, as discussed below.

FIG. 23 is another isometric side view of the jaw **2104** of FIG. 21. As illustrated, the jaw **2104** further includes a contact plate **2302**. The contact plate **2302** provides a structural location where the supply conductor **2116** (FIG. 21) may be coupled to the jaw **2104** to convey electrical energy thereto. In some embodiments, the contact plate **2302** may define a central aperture **2304**, a plurality of holes **2306**, and a through hole **2308**. The central aperture **2304** may be configured to co-axially align with the central aperture **2112** (FIG. 21) of the jaw holder **2106** to receive an axle (e.g., the first axle **804a** of FIGS. 9 and 10A-10B) therethrough. The holes **2306** may prove advantageous in helping secure the jaw **2104** to the jaw holder **2106** (FIG. 21) during an injection molding process, as discussed below. The through hole **2308** may prove advantageous in helping couple the supply conductor **2116** to the contact plate **2302** and in helping lock the jaw **2104** to the jaw holder **2106**, as discussed more below.

In some embodiments, the hook member **2202** and the contact plate **2302** may be made of electrically-conductive materials, such as a metal, and the isolator **2204** may be made of a non-conductive material, such as ceramic or a high strength, high temperature plastic. In other embodiments, the isolator **2204** may also be made of an electrically-conductive material, without departing from the scope of the disclosure.

The hook member **2202** and the contact plate **2302** may each be machined from a larger piece of material or may alternatively be manufactured, such as through metal injection molding (MIM), machining, laser cutting, forming (bending), stamping, 3D printing, or any combination thereof. The isolator **2204** may be machined or may be molded using ceramic injection molding (CIM).

To assemble the jaw **2104**, the shank **2206** of the hook member **2202** is received into the central passageway **2208** and the hook member **2202** may then be coupled to the

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isolator **2204**. In at least one embodiment, the isolator **2204** may be brazed to the hook member **2202** at a radial shoulder **2308** defined on the shank **2206**. In such embodiments, this brazed joint may prove advantageous in providing a repeatable seal that prevents bioburden and improves cleanability and sterilization of the end effector **2102** (FIG. 21). In addition, the brazed joint may help stiffen the end effector **2102** as compared to conventional hook-type end effectors.

The contact plate **2302** may then be coupled to the hook member **2202**. Consequently, electrical energy conveyed to the contact plate **2302** will be transmitted to the hook member **2202**. In some embodiments, the planar surface **2210** at the end of the shank **2206** may be resistance or laser welded to the contact plate **2302**. In other embodiments, however, the shank **2206** may be coupled to the contact plate **2302** at other locations or in other ways, such as by using one or more mechanical fasteners.

FIGS. 24A and 24B are front and back views, respectively, of the first portion **2118a** of the jaw holder **2106** following a first assembly sequence, according to one or more embodiments. The first portion **2118a** may be injection molded or otherwise formed or situated over a portion of the contact plate **2302**.

In FIG. 24A, the first portion **2118a** provides and otherwise defines a cable passage **2402** that communicates with the contact plate **2302**. As discussed below, the electrical conductor **2114** (FIG. 21) may be routed through the cable passage **2402** to allow the supply conductor **2116** (FIG. 21) to electrically communicate with (i.e., transmit electrical energy to) the contact plate **2302**. In some embodiments, one or more retention features **2404** may be provided in the cable passage **2402** to help capture the electrical conductor **2114**, as discussed below. In other embodiments, however, the cable passage **2402** may be formed in the contact plate **2302**, without departing from the scope of the disclosure.

In FIG. 24B, the first portion **2118a** may further provide an access passage **2406** eccentric to the central aperture **2112**. The access passage **2406** operates similar to the access passage **1806** of FIGS. 18B, 19, and 20B) and may be best understood with reference thereto. The access passage **2406** communicates with the through hole **2308** (FIG. 24A) defined in the contact plate **2302**. The access passage **2406** and the through hole **2308** cooperatively facilitate access to the contact plate **2302**, which may help in the process of coupling the supply conductor **2116** to the contact plate **2302**, as described herein.

FIG. 25 depicts the electrical conductor **2114** received within the first portion **2118a** of the jaw holder **2106**. Following the first assembly sequence that produces the first portion **2118a**, the electrical conductor **2114** may be coupled to and placed in electrical communication with the jaw **2104**. More specifically, the electrical conductor **2114** may be routed through and received by the cable passage **2402**. A portion of the insulation layer may be stripped from the electrical conductor **2114** to expose an end of the supply conductor **2116**, and the exposed portion of the supply conductor **2116** may be positioned adjacent the contact plate **2302**. The supply conductor **2116** may then be coupled to the contact plate **2302**, such as through resistance welding, crimping, or soldering. The coaxially aligned through hole **2308** and access passage **2406** (FIG. 24B) allows a resistance welder access for electrodes to form an opposing contact weld.

The retention features **2404** may be similar to or the same as the retention features **1804** of FIGS. 18A and 19 and, therefore, may be configured to engage the outer insulative layer of the electrical conductor **2114** and thereby help retain

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the electrical conductor **2114** within the cable passage **2402**. The retention features **2404** substantially prevent the electrical conductor **2114** from reversing back through the cable passage **2402**, which may prove advantageous in providing strain relief on the electrical conductor **2114** by helping to mitigate strain over several cycles of using the end effector **2102** (FIG. 21). Moreover, the retention features **2404** may prove advantageous in helping prevent the electrical conductor **2114** from moving during a subsequent overmold shot used to form the second portion **2118b** (FIGS. 26A and 26B).

FIGS. 26A and 26B are front and back views, respectively, of the end effector **2102** following an injection molding process that forms the second portion **2118b** of the jaw holder **2106**, according to one or more embodiments. The second portion **2118b** may be formed over the first portion **2118a** and the magnitude of the injection pressure may be managed to prevent excess flash. The injection molding process may alternately be referred to as an “overmold shot.”

During the overmold shot, the material for the second portion **2118b** (e.g., plastic) fills and encapsulates a cavity **2602** that contains the contact plate **2302** (FIGS. 23 and 25) and the exposed portion of the supply conductor **2116** (FIG. 25). Accordingly, the overmold shot electrically isolates and insulates the contact plate **2302** and the adjacent exposed supply conductor **2116**. Moreover, as seen in FIG. 26B, the overmold shot may also fill in the access passage **2406**. Furthermore, the material of the second portion **2118b** (e.g., plastic) may also fill in the holes **2306** (FIG. 23) defined in the contact plate **2303** and may encapsulate the mold profile **2212** (FIG. 22) defined on the isolator **2204**. In addition, the material for the second portion **2118b** may also flow into a clearance gap or annulus defined between the inner diameter of the central passageway **2208** (FIG. 22) and the outer diameter of the shank **2206** (FIG. 22). As will be appreciated, filling in the cavity **2602**, the access passage **2406**, the holes **2306**, the clearance gap, and overmolding the mold profile **2212** provides interlocking features that help lock the first and second portions **2118a,b** together and prevent separation.

Accordingly, the overmold shot encapsulates and electrically isolates the supply conductor **2116** and the jaw **2104** from adjacent electrically-conductive parts of the end effector **2102** (FIG. 21). Consequently, the electrical energy supplied to the jaw **1604** may have a reduced risk of inadvertent tissue damage due to unintended current leakage. Moreover, the two overmolding shots also help fill in cracks and crevices in the end effector **2102** that might present a bioburden risk.

FIG. 27 is an enlarged isometric view of another example end effector **2702** that may be used with the surgical tool **600** of FIG. 6, according to one or more embodiments. Accordingly, in some applications, the end effector **2702** of FIG. 27 may replace the end effector **604** of FIGS. 6 and 8-12. The end effector **2702** may be similar in some respects to the end effector **604** and therefore may be best understood with reference thereto, where like numerals will represent like component not described again.

Similar to the end effector **604** of FIGS. 6 and 8-12, the end effector **2702** includes the first and second jaws **610**, **612** rotatably mounted to the distal clevis **802a** at the first axle **804a**. The end effector **2702** also includes the first and second jaw holders **902a,b** that receive and seat the first and second jaws **610**, **612**, respectively, for corresponding movement (rotation) therewith. Unlike the end effector **604** of

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FIGS. 6 and 8-12, however, the first axle **804a** comprises a headed axle pin, as discussed below.

FIG. 28 is a cross-sectional front view of the end effector **2702** of FIG. 27. As illustrated, first axle **804a** has a first end **2802a** and a second end **2802b**, and an enlarged-diameter head **2804** is provided and otherwise defined at the first end **2802a**. The head **2804** exhibits a first diameter **2806a**, whereas the second end **2802b** of the first axle **804a** exhibits a second diameter **2806b** that is smaller than the first diameter **2806a**.

FIG. 28 also depicts how the first axle **804a** may be mounted to the distal clevis **802a**, which correspondingly mounts the jaws **610**, **612** for rotation about the first axle **804a**. The first arm **1004a** defines a first aperture **2808a** sized and otherwise configured to receive the first end **2802a** and the head **2804**, and the second arm **1004b** defines a second aperture **2808b** configured to receive and secure the second end **2802b**. The first axle **804a** may be secured to the distal clevis **802a** at the second end **2802b** via a variety of means, as discussed below. When securing the first axle **804a** at the second end **2802b**, the enlarged-diameter head **2804** is able to apply a compressive load (force) against the first and second jaw holders **902a,b** at a radial shoulder **2810**, which results in a zero tolerance stack without gaps between the jaw holders **902a,b**, thus assuring point-to-point contact while opening and closing the jaws **610**, **612**.

FIG. 29 is an exploded view of the end effector **2702** of FIG. 27. To assemble the end effector **2702**, the first and second jaw holders **902a,b** may first be positioned in an opening **2902** defined between the opposing arms **1004a,b** of the distal clevis **802a**. The second end **2802b** of the first axle **804a** may then be progressively extended through the first aperture **2808a** in the first arm **1004a**, the central apertures **1102a,b** of the jaw holders **902a,b**, respectively, and lastly the second aperture **2808b** in the second arm **1004b**. The first end **2802a** and the head **2804** may then be received in the first aperture **2808a**.

To secure the first axle **804a** to the distal clevis **802a**, the second end **2802b** may be coupled or attached to the distal clevis **802a** at the second aperture **2808b**. In some embodiments, the second end **2802b** may be welded or brazed to the distal clevis **802a** at the second aperture **2808b**. In other embodiments, the second end **2802b** may be threaded into the second aperture **2808b**. In yet other embodiments, the second end **2802b** may be secured to the second aperture **2808b** end by orbital riveting the outer surface of the second end **2802b**. In even further embodiments, the second end **2802b** may be received within the second aperture **2808b** via an interference or shrink fit.

While the second end **2802b** is being attached to the distal clevis **802a** at the second aperture **2808b**, a compressive load (force) may be applied along the first axle **804a** at the first end **2802a**. The compressive load may force the radial shoulder **2810** of the enlarged-diameter head **2804** against the first and second jaw holders **902a,b**, and thereby remove any gaps between the jaw holders **902a,b** to provide a zero tolerance stack. This may prove advantageous in trapping the jaws **610**, **612** within the assembly such that the jaws **610**, **612** need not be welded to the respective jaw holders **902a,b**. Consequently, the jaws **610**, **612** may be made out of harder materials, such as 420 stainless steel or a ceramic, which do not exhibit good weld characteristics. Moreover, securing the first axle **804a** to the distal clevis **802a** while a compressive load (force) is applied ensures that opposing bearing surfaces **2904** of the jaws **610**, **612** are maintained parallel to one another during operation. This may prove

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advantageous in assuring point-to-point contact while opening and closing the jaws **610**, **612**.

Embodiments disclosed herein include:

A. A surgical tool that includes a drive housing, an elongate shaft that extends from the drive housing, an end effector arranged at a distal end of the elongate shaft and having a jaw and a jaw holder that secures the jaw, a wrist that couples the end effector to the elongate shaft and includes a distal clevis having an axle that rotatably mounts the jaw holder to the distal clevis, and an electrical conductor that extends from the drive housing and supplies electrical energy to the jaw via a supply conductor, wherein at least one of the jaw holder and the axle is made of a non-conductive material that insulates the distal clevis from the electrical energy provided to the jaw.

B. An end effector that includes a distal clevis, an axle mounted to the distal clevis, a jaw holder rotatably mounted to the axle, a jaw secured to the jaw holder such that rotation of the jaw holder correspondingly rotates the jaw, and an electrical conductor that supplies electrical energy to the jaw via a supply conductor, wherein at least one of the jaw holder and the axle is made of a non-conductive material that insulates the distal clevis from the electrical energy provided to the jaw.

C. A method of operating a surgical tool that includes positioning the surgical tool adjacent a patient for operation, the surgical tool including a drive housing, an elongate shaft that extends from the drive housing, an end effector arranged at a distal end of the elongate shaft and having a jaw and a jaw holder that secures the jaw, a wrist that couples the end effector to the elongate shaft and includes a distal clevis having an axle that rotatably mounts the jaw holder to the distal clevis, wherein at least one of the jaw holder and the axle is made of a non-conductive material, and an electrical conductor that extends from the drive housing to the jaw. The method further including supplying electrical energy to the jaw via a supply conductor of the electrical conductor, and insulating the distal clevis from the electrical energy provided to the jaw with one or both of the jaw holder and the axle.

Each of embodiments A, B, and C may have one or more of the following additional elements in any combination: Element 1: wherein the end effector is configured for monopolar operation. Element 2: wherein the end effector is configured for bipolar operation. Element 3: wherein the non-conductive material is selected from the group consisting of a ceramic, a plastic, a thermoplastic or thermosetting polymer, a composite material, hard rubber, a metal with an insulative coating, and any combination thereof. Element 4: wherein the jaw is a first jaw, the jaw holder is a first jaw holder, and the end effector further comprises a second jaw and a second jaw holder that secures the second jaw, wherein the first and second jaw holders are rotatably mounted to the distal clevis at the axle, a first end cap that receives a first end of the axle and is secured within a first slot defined in the distal clevis, and a second end cap that receives a second end of the axle and is secured within a second slot defined in the distal clevis. Element 5: wherein the first jaw holder comprises a first portion that receives and secures the first jaw, and a second portion coupled to the first portion. Element 6: wherein the axle is made of the non-conductive material and defines a channel that receives the electrical conductor, and wherein the end effector further comprises a contact plate mounted to the axle adjacent the first and second jaws and in electrical communication with the supply conductor to transfer the electrical energy to the first and second jaws. Element 7: wherein the jaw provides a contact plate having

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the supply conductor coupled thereto and the jaw holder is made of at least one non-conductive material and comprises a first portion injection molded to the jaw and defining a cable passage through which the electrical conductor is extendable, and a second portion overmolded to the first portion to encapsulate and electrically insulate the contact plate and an exposed portion of the supply conductor. Element 8: further comprising one or more retention features defined in the cable passage to retain the electrical conductor within the cable passage.

Element 9: wherein the non-conductive material is selected from the group consisting of a ceramic, a plastic, a thermoplastic or thermosetting polymer, a composite material, hard rubber, a metal with an insulative coating, and any combination thereof. Element 10: wherein the jaw is a first jaw, the jaw holder is a first jaw holder, and the end effector further comprises a second jaw and a second jaw holder that secures the second jaw, wherein the first and second jaw holders are rotatably mounted to the distal clevis at the axle, a first end cap that receives a first end of the axle and is secured within a first slot defined in the distal clevis, and a second end cap that receives a second end of the axle and is secured within a second slot defined in the distal clevis. Element 11: wherein the supply conductor is secured to the first jaw at a pocket defined in the first jaw. Element 12: wherein the first jaw holder comprises a first portion that receives and secures the first jaw, and a second portion coupled to the first portion. Element 13: wherein the first portion is made of ceramic and the second portion is made of a plastic overmolded onto the first portion. Element 14: wherein the axle is made of the non-conductive material and defines a channel that receives the electrical conductor, and wherein the end effector further comprises a contact plate mounted to the axle adjacent the first and second jaws and in electrical communication with the supply conductor to transfer the electrical energy to the first and second jaws. Element 15: wherein the contact plate comprises an arcuate body having a contact surface positioned adjacent an arcuate bottom surface of each of the first and second jaws. Element 16: wherein the jaw provides a contact plate having the supply conductor coupled thereto and the jaw holder is made of at least one non-conductive material and comprises a first portion injection molded to the jaw and defining a cable passage through which the electrical conductor is extendable, and a second portion overmolded to the first portion to encapsulate and electrically insulate the contact plate and an exposed portion of the supply conductor. Element 17: further comprising one or more retention features defined in the cable passage to retain the electrical conductor within the cable passage. Element 18: wherein the jaw further comprises a hook member, a shank that extends from the hook member and is coupled to the contact plate, and an isolator that defines a central passageway to receive the shank, wherein the hook member and the contact plate are made of a conductive material, and the isolator is made of a non-conductive material.

By way of non-limiting example, exemplary combinations applicable to A, B, and C include: Element 4 with Element 5; Element 4 with Element 6; Element 7 with Element 8; Element 10 with Element 11; Element 10 with Element 12; Element 12 with Element 13; Element 10 with Element 14; and Element 14 with Element 15.

Therefore, the disclosed systems and methods are well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the teachings of the present disclosure may be modified and practiced in

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different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered, combined, or modified and all such variations are considered within the scope of the present disclosure. The systems and methods illustratively disclosed herein may suitably be practiced in the absence of any element that is not specifically disclosed herein and/or any optional element disclosed herein. While compositions and methods are described in terms of “comprising,” “containing,” or “including” various components or steps, the compositions and methods can also “consist essentially of” or “consist of” the various components and steps. All numbers and ranges disclosed above may vary by some amount. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range is specifically disclosed. In particular, every range of values (of the form, “from about a to about b,” or, equivalently, “from approximately a to b,” or, equivalently, “from approximately a-b”) disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. Moreover, the indefinite articles “a” or “an,” as used in the claims, are defined herein to mean one or more than one of the elements that it introduces. If there is any conflict in the usages of a word or term in this specification and one or more patent or other documents that may be incorporated herein by reference, the definitions that are consistent with this specification should be adopted.

As used herein, the phrase “at least one of” preceding a series of items, with the terms “and” or “or” to separate any of the items, modifies the list as a whole, rather than each member of the list (i.e., each item). The phrase “at least one of” allows a meaning that includes at least one of any one of the items, and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, the phrases “at least one of A, B, and C” or “at least one of A, B, or C” each refer to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

What is claimed is:

1. A surgical tool, comprising:

a drive housing;

an elongate shaft that extends from the drive housing;

an end effector arranged at a distal end of the elongate shaft and having a jaw and a jaw holder that receives and seats the jaw;

a wrist that couples the end effector to the elongate shaft and includes a distal clevis and an axle extending through the jaw, the jaw holder, and the distal clevis to rotatably mount the jaw holder to the distal clevis, the distal clevis defining an open-ended slot extending to an outer periphery of the distal clevis in a direction perpendicular to a pivot axis of rotation of the axle;

an end cap that receives an end of the axle and is secured within the open-ended slot;

a pair of drive cables extending from the drive housing and terminating at the jaw holder; and

an insulated electrical conductor separate from the pair of drive cables and extending from the drive housing and terminating at the jaw to supply electrical energy to the jaw,

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wherein the jaw holder and the axle are made of a non-conductive material that insulates the distal clevis from the electrical energy provided to the jaw.

2. The surgical tool of claim 1, wherein the end effector is configured for monopolar operation.

3. The surgical tool of claim 1, wherein the end effector is configured for bipolar operation.

4. The surgical tool of claim 1, wherein the non-conductive material is selected from the group consisting of a ceramic, a plastic, a thermoplastic or thermosetting polymer, a composite material, hard rubber, a metal with an insulative coating, and any combination thereof.

5. The surgical tool of claim 1, wherein the jaw is a first jaw, the jaw holder is a first jaw holder, and the open-ended slot is a first open-ended slot, the end cap is a first end cap, and the end of the axle is a first end of the axle, the end effector further comprises:

a second jaw and a second jaw holder that receives and seats the second jaw, wherein the first and second jaw holders are rotatably mounted to the distal clevis at the axle; and

a second end cap that receives a second end of the axle and is secured within a second open-ended slot defined in the distal clevis, the second open-ended slot extending in the direction perpendicular to the pivot axis of rotation of the axle.

6. The surgical tool of claim 5, wherein the first jaw holder comprises:

a first portion that receives and secures the first jaw; and a second portion overmolded onto the first portion and defining a pulley that receives the pair of drive cables.

7. The surgical tool of claim 5, wherein the axles defines a channel that receives a channel that receives the insulated electrical conductor, and

wherein the end effector further comprises a contact plate mounted to the axle adjacent the first and second jaws and in electrical communication with a supply conductor of the insulated electrical conductor to transfer the electrical energy to the first and second jaws.

8. The surgical tool of claim 1, wherein the jaw provides a contact plate having a supply conductor of the insulated electrical conductor coupled thereto and comprises:

a first portion injection molded to the jaw and defining a cable passage through which the insulated electrical conductor is extendable; and

a second portion overmolded to the first portion to encapsulate and electrically insulate the contact plate and an exposed portion of the supply conductor.

9. The surgical tool of claim 1, further comprising a pulley defined by the jaw holder and configured to receive and seat the pair of drive cables.

10. The surgical tool of claim 1, further comprising:

a first recess defined in the jaw holder to receive and seat the jaw; and

a spacer arranged laterally adjacent the jaw and received within a second recess defined in the jaw holder.

11. An end effector, comprising:

a distal clevis;

an end cap that receives an end of an axle and is secured to the distal clevis at an open-ended slot defined in the distal clevis, the open-ended slot extending to an outer periphery of the distal clevis in a direction perpendicular to a pivot axis of rotation of the axle;

a jaw holder rotatably mounted to the axle;

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a jaw secured to the jaw holder such that rotation of the jaw holder correspondingly rotates the jaw, wherein the axle extends through the jaw, the jaw holder, and the distal clevis; and

an insulated electrical conductor terminating at the jaw to supply electrical energy to the jaw,

wherein the jaw holder and the axle are made of a non-conductive material that insulates the distal clevis from the electrical energy provided to the jaw.

12. The end effector of claim 11, wherein the non-conductive material is selected from the group consisting of a ceramic, a plastic, a thermoplastic or thermosetting polymer, a composite material, hard rubber, a metal with an insulative coating, and any combination thereof.

13. The end effector of claim 11, wherein the jaw is a first jaw, the jaw holder is a first jaw holder, the end cap is a first end cap, the end of the axle is a first end of the axle, and the open-ended slot is a first open-ended slot, the end effector further comprises:

a second jaw and a second jaw holder that secures the second jaw, wherein the first and second jaw holders are rotatably mounted to the distal clevis at the axle; and

a second end cap that receives a second end of the axle and is secured within a second open-ended slot defined in the distal clevis, the second open-ended slot extending in the direction perpendicular to the pivot axis of rotation of the axle.

14. The end effector of claim 13, wherein a supply conductor of the insulated electrical conductor is secured to the first jaw at a pocket defined in the first jaw.

15. The end effector of claim 13, wherein the first jaw holder comprises:

a first portion that receives and secures the first jaw; and a second portion overmolded onto the first portion.

16. The end effector of claim 15, wherein the first portion is made of ceramic and the second portion is made of a plastic overmolded onto the first portion.

17. The end effector of claim 13, wherein the axles defines a channel that receives the insulated electrical conductor, and

wherein the end effector further comprises a contact plate mounted to the axle adjacent the first and second jaws and in electrical communication with a supply conduc-

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tor of the insulated electrical conductor to transfer the electrical energy to the first and second jaws.

18. The end effector of claim 17, wherein the contact plate comprises an arcuate body having a contact surface positioned adjacent an arcuate bottom surface of each of the first and second jaws.

19. The end effector of claim 11, wherein the jaw provides a contact plate having a supply conductor of the insulated electrical conductor coupled thereto and comprises:

a first portion injection molded to the jaw and defining a cable passage through which the insulated electrical conductor is extendable; and

a second portion overmolded to the first portion to encapsulate and electrically insulate the contact plate and an exposed portion of the supply conductor.

20. The end effector of claim 11, further comprising:

a first recess defined in the jaw holder to receive and seat the jaw; and

a spacer arranged laterally adjacent the jaw and received within a second recess defined in the jaw holder.

21. A method of operating a surgical tool, comprising: positioning the surgical tool adjacent a patient for operation, the surgical tool including:

a drive housing;

an elongate shaft that extends from the drive housing;

an end effector arranged at a distal end of the elongate shaft and having a jaw and a jaw holder that secures the jaw;

a wrist that couples the end effector to the elongate shaft and includes a distal clevis having an axle that rotatably mounts the jaw holder to the distal clevis, the distal clevis defining an open-ended slot extending to an outer periphery of the distal clevis in a direction perpendicular to an axis of rotation of the axle, wherein an end cap that receives an end of the axle is secured at the open-ended slot; and

an insulated electrical conductor extending from the drive housing to the jaw;

supplying electrical energy to the jaw via the insulated electrical conductor; and

insulating the distal clevis from the electrical energy provided to the jaw with one or both of the jaw holder and the axle, wherein at least one of the jaw holder and the axle is made of a non-conductive material.

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